AN INVESTIGATION OF ALTERNATIVE DEPLOYMENT DOCTRINES FOR AN INTEGRATED SENSOR ARRAY IN BASE DEFENSE

by

Michael Matthew Schneider

United States
Naval Postgraduate School

THESIS

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Michael Matthew Schneider

Thesis Advisor: G. F. Lindsay

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Michael Matthew Schneider
Major, United States Army
B.A., Texas A&M University, 1962

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ABSTRACT

A mathematical model describing the detection activities of an integrated sensor array containing radars, visual devices and remote sensors is presented. Using the programmed model, infiltration of a base defense area is simulated with a computer and results are obtained for various array deployment schemes. A comparative analysis of these results is conducted using game and decision theory and a general conclusion concerning an optimal sensor deployment doctrine is derived. The complete computer program is described in the text of the study and is contained as an appendix.

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ACKNOWLEDGEMENT

The assistance of two fellow students in selecting the infiltration routes and the locations of the sensors was required in order to obtain realistic data unbiased by knowledge of the procedures used in the study. For performing these tedious exercises in map reading, the aid of Major Richard S. Miller, a U.S. Army Infantry Officer who selected the infiltration routes, and Major George L. Moses, a U.S. Army Field Artillery Officer who selected the sensor locations, is gratefully acknowledged.

I. SUMMARY

A requirement exists within the U.S. Army for analytic techniques which provide quick answers to problems involving equipment employment and tactical doctrine. Such a technique was used within this study to investigate the deployment doctrine for an integrated sensor system used in a base defense role.

A series of assumptions concerning the relationships of terrain, vegetation, enemy movement, and sensor detection capabilities allowed the construction of several mathematical models to describe a base defense problem within a particular scenario. These models were used to develop a computer program used for simulation of the problem. By changing the specific placements of the sensors in accordance with several different deployment doctrines, an indication of the relative effectiveness of various doctrine was obtained.

The model made use of a simulated base camp located within a selected ten by ten kilometer area. For sensor resources, the base commander had available three ground surveillance radars, four night observation devices, and thirty unattended ground sensors where each system had performance characteristics which represented composites of systems within the U.S. Army inventory. These devices were deployed to counter a 360° infiltration threat.

Game and decision theory were used in a comparative analysis of the results obtained from the computer simulation of eight deployment schemes against infiltration on twelve preselected routes. It was concluded that doctrine should not restrict the commander's options in placing the radars and visual devices, however, the deployment of the remote sensors should be limited by doctrine to the vicinity of the base perimeter.

This study also pointed to the use of quick, simple mathematical models used with computer simulation to provide a capability for rapid analysis of small tactical situations.

II. INTRODUCTION

The experience of the U.S. Army during the conflict in Vietnam has emphasized the relative ineffectiveness of the intelligence and target acquisition resources available to support the highly developed firepower and mobility systems available to the field commander. Although refinement of doctrine and equipment to improve the airmobile effectiveness of U.S. forces has enabled the combat commander to engage a targeted enemy force within a relatively short time, successful identification and location of enemy forces continues to be one of the major problems of the U.S. forces. To help overcome this limitation the Army recently emphasized the development and employment of various surveillance, target acquisition, and night observation (STANO) devices. The emphasis in this area has led to the development of numerous devices - some quite successful and some not successful. Just to catalog the devices developed or being developed requires a large reference document [1].

As the more successful systems have entered the Army's inventory of equipment, it has become necessary to develop standard methods of employing this equipment in various combat situations. The U.S. Army Combat Developments Command (USACDC) has primary responsibility for the development of tactical doctrine within the Army. Project MASTER (Mobile Army Sensor/Target Acquisition Evaluation) at Fort

Hood, Texas, was chartered in the fall of 1969 with the responsibility for conducting quick field tests of selected sensor systems and extensive field tests of integrated sensor systems.

A special problem recognized during the conflict in Vietnam was that of defending the numerous bases spread throughout the country. These bases are of many types, such as logistical, artillery fire bases, and forward area landing zones. Often, limited personnel at these bases preclude extensive patrolling activities in defense of the base. Normally a 360° infiltration threat exists with possible rocket, mortar, or sapper (explosives) attack being the major concerns. Doctrine for base defense, not only for Vietnam but also in general, has been promulgated in Field Manual 31-81 (TEST), March, 1970, [2]. The purpose of this document is noted in paragraph 1-1 of the manual:

> "This manual provides guidance to commanders, staff officers, and other personnel concerned with the defense of various types of semipermanent bases, such as logistics installations, base camps, air fields, and air bases, under varying conditions of security that may exist in an area (theater) of operations."

The guidance mentioned is of a general nature, either relying on the reader's knowledge of the proper employment of detection devices or directing their attention to other documents [3], [4], which, while providing information about the relevant capabilities of different STANO systems, fail to provide guidance for use of integrated systems.

In order to help alleviate this gap in doctrine, the study described in this paper was initiated. The primary

purpose of the study was to develop a technique which would allow the comparison of various doctrines for the employment of sensing devices as part of an integrated sensor system. Ideally, this technique should allow various doctrines to be tested by deploying the sensor systems in a "realistic" environment. The results obtained using various test doctrines could then be compared. The use of techniques developed in this study permit the comparison of several doctrines without resorting to a field test.

A secondary objective of the study was the comparison of several doctrines for sensor deployment. The doctrines were drawn from Army publications and from variations in doctrine designed by the author.

In his speech to the U.S. Army Commander's Conference on 2 December 1970, Lieutenant General John Norton, Commanding General, U.S. Combat Developments Command, gave as a major challenge facing U.S. Army testing efforts the following:

> "To design and operate some kind of simulated or 'Breadboard' Battlefield which will allow us to 'Plug-in' new hardware and ideas to typical combat situations and to 'readout' useful results in a few days or weeks."

The technique used in the study described by this paper utilizes the simulated battlefield to compare various ideas on integrated sensor employment.

The assumptions used in the construction of a base defense model are outlined in Chapter III. The construction of the model is described in Chapter IV. The computer

program written to incorporate the model is explained in Chapter V and the program in its entirity is contained as an appendix to this study.

The results obtained using computer simulation of the base defense situation are contained in Chapter VI together with a comparative analysis of the tested doctrines. Chapter VII contains the conclusions and recommended extensions which have resulted from this study.

III. RATIONALE AND ASSUMPTIONS

In order to test various sensor deployment doctrines in a fairly realistic environment, it was necessary to quantify the variables which are found in such a situation. Such factors as variations in terrain, in enemy tactics, and in the operating characteristics of the sensing equipment had to be simplified and represented symbolically in a mathematical model. The techniques employed to simplify and quantify the salient features of a situation can best be classified as an art in which the success of the model depends on the facility of the modeler and his knowledge of the situation being represented. The assumptions used in this study and the underlying rationale for their use are explained in this chapter.

A. TERRAIN

In order to test various doctrines for employment of an integrated sensor system with a model it is necessary to carefully choose the terrain input. After a period of map study which included examination of the terrain in four areas - Southeast Asia; Fort Ord, California; Hunter Liggett Military Reservation, California; and Fort Hood, Texas - the area east of Hunter Liggett Military Reservation shown in Figure 1 was selected as the most representative of the terrains encountered during base defense. Some guidelines were contrived for selection of terrain so that the site

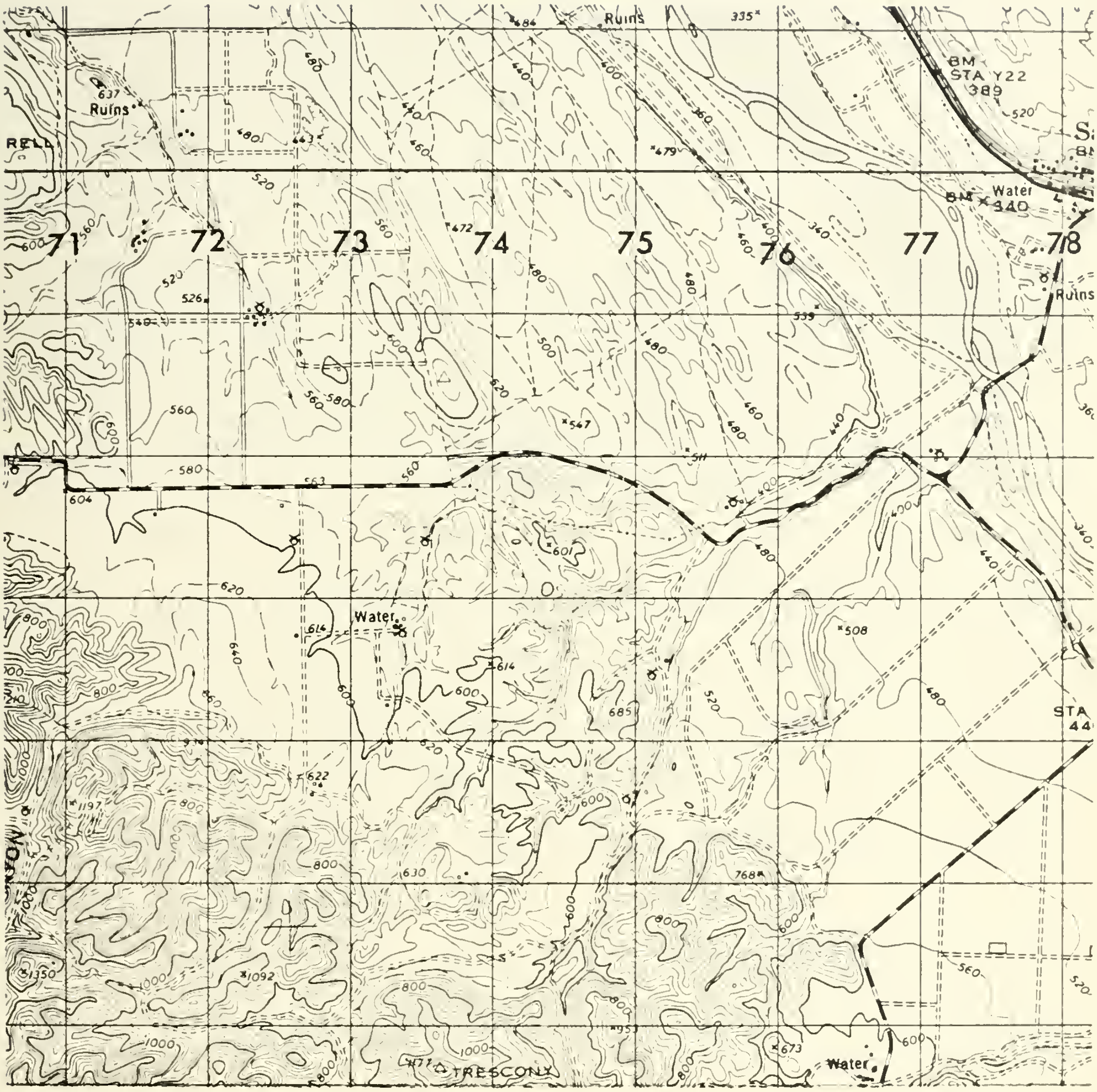


Figure 1. The Ten by Ten Kilometer Area of Operations. (From map sheet 1756 II, series V795, edition 5-AMS, King City)

would be representative of common base locations and would allow the comparison of various doctrines for employment of ground surveillance radars and night observation devices in an area where intervisibility (line-of-sight) characteristics varied widely. The terrain selected satisfied the guidelines almost perfectly. The guidelines were:

> Selecting a point in the center of an area as a feasible base location, the surrounding terrain should consist of approximately 180° of mountainous, heavily vegetated regions and 180° of flat, lightly vegetated terrain. These characteristics should extend fairly continuously for at least five kilometers in all directions. The importance of terrain considerations will become clearer upon examination of the doctrines used in the simulation.

The ten by ten kilometer area selected was divided into 10,000 one-hundred meter squares by imposing a two milimeter grid onto the map. The average elevation of each of these squares to the nearest ten feet was then computed by interpolation of the forty-foot-interval contour lines. These elevations were recorded utilizing an X-Y coordinate system as shown in Figure 2.

The elevation data was recorded on normal computer punch cards - 16 readings to a card, for a total of 625 elevation data cards.

The performance of any sensor is heavily dependent on the type of vegetation present in the target area. For this reason the vegetation characteristic of each of the 10,000 one-hundred meter squares was also recorded. A coding system was used to identify the vegetation characteristic as one of four types:

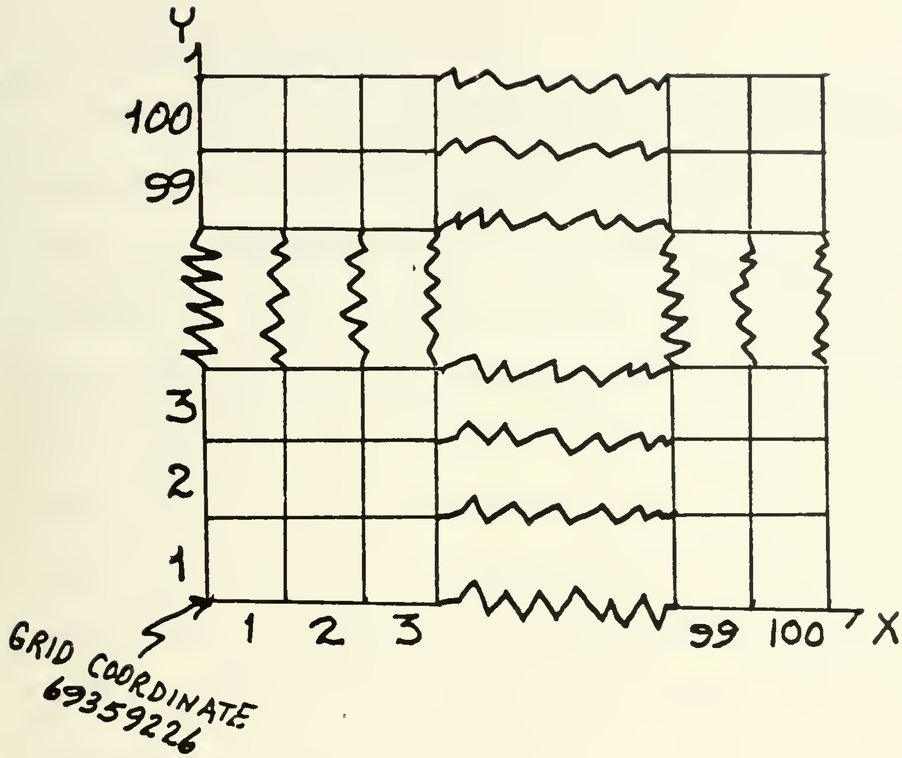


Figure 2. The Grid System.

1 - Open, little or no vegetation

2 - Lightly wooded, orchard

3 - Heavily wooded

4 - Water

These four classes of vegetation were the only ones available from the map study. Because of the limited availability of vegetation data, no attempt was made to incorporate average foliage heights or other more descriptive vegetation characteristics.

The vegetation characteristic of each square was recorded on a data deck arranged identically to the elevation data deck. The information was stored eighty squares to the card, requiring a 125 card vegetation data deck.

B. SENSOR SYSTEMS

The three types of sensor systems used in this model are composite representations of systems presently in use in the Army, or systems which have been tested and approved for procurement in the near future. Use was made of composite systems for security reasons and to permit the use of the model with future sensor systems as they are developed. The model can be easily modified to accept sensor systems of the same types as are presently represented but with different performance characteristics. The three systems utilized are listed below along with their pertinent performance values.

Since the composition, mission, and resources available vary widely among semipermanent bases, no basis of issue exists for the three types of sensor systems utilized in this problem. The procurement of detection devices as an aid for base defense is based on the base commander's need for such devices and the resources available to the area commander [2]. For the purposes of this study, the base commander is considered to have three operational radars and four observation devices. These assigned resources are based on sector coverage of each of these systems as described below and allows the coverage of all or almost all of 360° by each of the systems if employed symmetrically. Ten strings of three sensors each are assumed available to the Base Commander to satisfy the requirement for unattended ground sensors.

1. Ground Surveillance Radar

The ground surveillance radar utilized in the model is characterized by the following performance values. The radar has a minimum detection range of 400 meters and a maximum effective detection range of 3200 meters. Targets can be detected when they possess a radial velocity between one and sixty kilometers per hour inclusive. The radar utilizes a continuous sector scan of 110° width. Sequential automatic range gating is used by the radar in sectors of 400 meters depth requiring one minute per sector. The radar possesses a moderate foliage penetration capability with sixty percent of optimum effectiveness in lightly wooded (Type 2) terrain, and twenty percent of optimum effectiveness in heavily wooded (Type 3) terrain. An important aid to the line-of-sight capability of the radar is the location of the antenna on a mast twenty meters high. The nominal probability of detection of personnel within the effective range is assumed to be 0.90 under optimum conditions.

2. Night Observation Device

The night observation device utilized in the model has a maximum effective range of 1600 meters assuming at most light cloud cover, with the moon between one and three quarters. Each device has a field of view of 9° and is assigned (within the model) a sector of 90° to be covered in 9° increments. The detection ability of an observer using this device is degraded only moderately because of vegetation.

Device effectiveness is considered to be eighty percent of optimum against targets in a lightly wooded (Type 2) area and forty percent of optimum in a heavily wooded (Type 3) area. The optimum probability of detection for the night observation device is considered to be range dependent, where

$$\text{Probability of Detection} = \begin{cases} 0.90, & \text{for ranges less than 400 meters} \\ 0.90\ (400/\text{range}), & \text{for ranges greater than 400 meters.} \end{cases}$$

In contrast to the doppler-operating ground surveillance radar, the night observation device depends primarily on the human eye as the actual detecting device. It would appear reasonable that personnel will be extremely cautious when searching the area immediately in front of their observation post. Therefore, the detection probability is assumed to have its maximum value of 0.90 until the range is sufficient (400 meters) for reducing self-preservation induced caution. Thereafter, the probability of detection is assumed to be roughly inversely proportional to the range of the target. These assumptions appear tenable and are not inconsistent when contrasted with the varying formulas used to determine detection probabilities in the literature [5], [7].

3. Unattended Ground Sensors

The unattended ground sensor utilized in the model is of the Seismic/Acoustic type with a radius of detection of 40 meters. The sensors are deployed in groups of three (called strings) with individual sensors located

approximately 200 meters apart in accordance with current Army doctrine [3]. The reliability of the individual sensors, often a problem in actual deployment, was not considered in the model. The probability of detection of a target within the sensor radius of detection is considered to be 0.90.

Considering thirty sensors with a radius of detection of 40 meters and a detection probability of .90 it would appear that the probability of detecting an intruder with random (non-overlapping) deployment of sensors would be calculated as follows:

$$\begin{array}{c}\text{Probability}\\ \text{of Detection}\\ \text{(PD)}\end{array} = \left(\begin{array}{c}\text{Sensor}\\ \text{Detection}\\ \text{Probability}\end{array}\right)\left(\begin{array}{c}\text{Number of}\\ \text{Sensors}\\ \text{Deployed}\end{array}\right)\left(\begin{array}{c}\text{The Area}\\ \text{Covered by}\\ \text{One Sensor}\end{array}\right)\Bigg/\left(\begin{array}{c}\text{The Total}\\ \text{Area to be}\\ \text{Protected}\end{array}\right)$$

$$PD = \frac{(.90)\ (30)\ (40)^2\ \pi}{(5000)^2\ \pi}\ ,$$

$$PD = 0.00173.$$

This rather low value is the instantaneous probability of detecting the intruder. To arrive at a more meaningful figure, the intruder's movement and the time he spends in the base defense area must be considered. The method used to move the intruder groups will be explained in detail below. It is sufficient for the sake of calculating the detection probability of the thirty remore sensors to know that the intruder groups are moved discretely from one 100-meter square to the next. At each move a check for detection is made. Each unattended ground sensor is placed within a specific 100-meter square. If the intruder enters

the square, then the probability of detection is calculated by:

$$PD = \left(\begin{array}{c}\text{Sensor}\\ \text{Detection}\\ \text{Probability}\end{array}\right)\left(\begin{array}{c}\text{The Area}\\ \text{Covered by}\\ \text{the Sensor}\end{array}\right)\Big/\left(\begin{array}{c}\text{The Area}\\ \text{of the}\\ \text{Square}\end{array}\right),$$

$$PD = \frac{(0.90)\ (40)^2\ \pi}{(100)^2},$$

and $PD = 0.4526.$

Considering that there are 30 sensors available for deployment and that there are approximately

$$\left(\frac{(5000)^2\ \pi}{(10000)^2\ \pi}\right)\left(10{,}000\right) = 7{,}857$$

squares within the five kilometer radius base defense area, and that each intruder group makes an average of 46.5 discrete grid square moves, then the probability that an intruder is detected by a randomly placed sensor is:

$$PD = \left(\begin{array}{c}\text{Number of}\\ \text{Moves Made}\\ \text{by Intruder}\end{array}\right)\left(\begin{array}{c}\text{Probability that the}\\ \text{Intruder Moves to a}\\ \text{Square with a Sensor}\end{array}\right)\left(\begin{array}{c}\text{Probability Intruder}\\ \text{is Detected by a Sensor}\\ \text{Located in the Square}\end{array}\right)$$

$$PD = (46.5)\ \left(\frac{30}{7857}\right)\ (0.4526),$$

$$PD = 0.08.$$

This is a somewhat more realistic estimate of the chance of detecting an intruder with randomly placed sensors. When it is considered that the intruder will not move randomly, but will be constrained by the terrain and his objective, and that the unattended ground sensors will be

placed in the most likely infiltration areas as determined by a map reconnaissance and the specified doctrine, then the chance for detection of the intruder utilizing thirty sensors appears reasonable.

C. INTRUDER MOVEMENTS

In order to test the various sensor system deployment doctrines it was necessary to generate some type of penetration through the base defense area. Randomized intruder routes were considered. Randomizing the routes would require selection of entry points at random from among 0° to 360°. Intruders would then be moved toward the base in a random manner under the constraints of target and terrain. This method was rejected for two major reasons. In order that the deployment doctrines be compared it appeared that the intrusion against systems deployed in accordance with each specific doctrine should be constant. Random movement of intruders appears to be an unrealistic action on the part of the enemy.

Instead, it was decided that twelve different penetration efforts would be simulated against each deployed system. It appeared that three infiltrators per quadrant would provide an adequate test of the systems used to protect this area. These intruders enter the base defense area from twelve points distributed uniformly around the 360° defense perimeter, with their individual routes within the defense area remaining constant throughout the simulation runs. To provide realism in developing the scenario, an experienced

Infantry Officer trained in patrolling tactics assisted in selecting the infiltration routes. The officer was supplied with a map of the area with twelve indicated starting points, each located six kilometers from the known objective. He was requested to mark intrusion routes in accordance with the following guidelines:

1. Intruders will travel in groups of 2-5 men.

2. Travel will be entirely at night.

3. Speed is important to the intruders, but should be balanced with a desire to avoid detection.

4. The intruders have a general knowledge of U.S. detection efforts, but not specific knowledge of techniques.

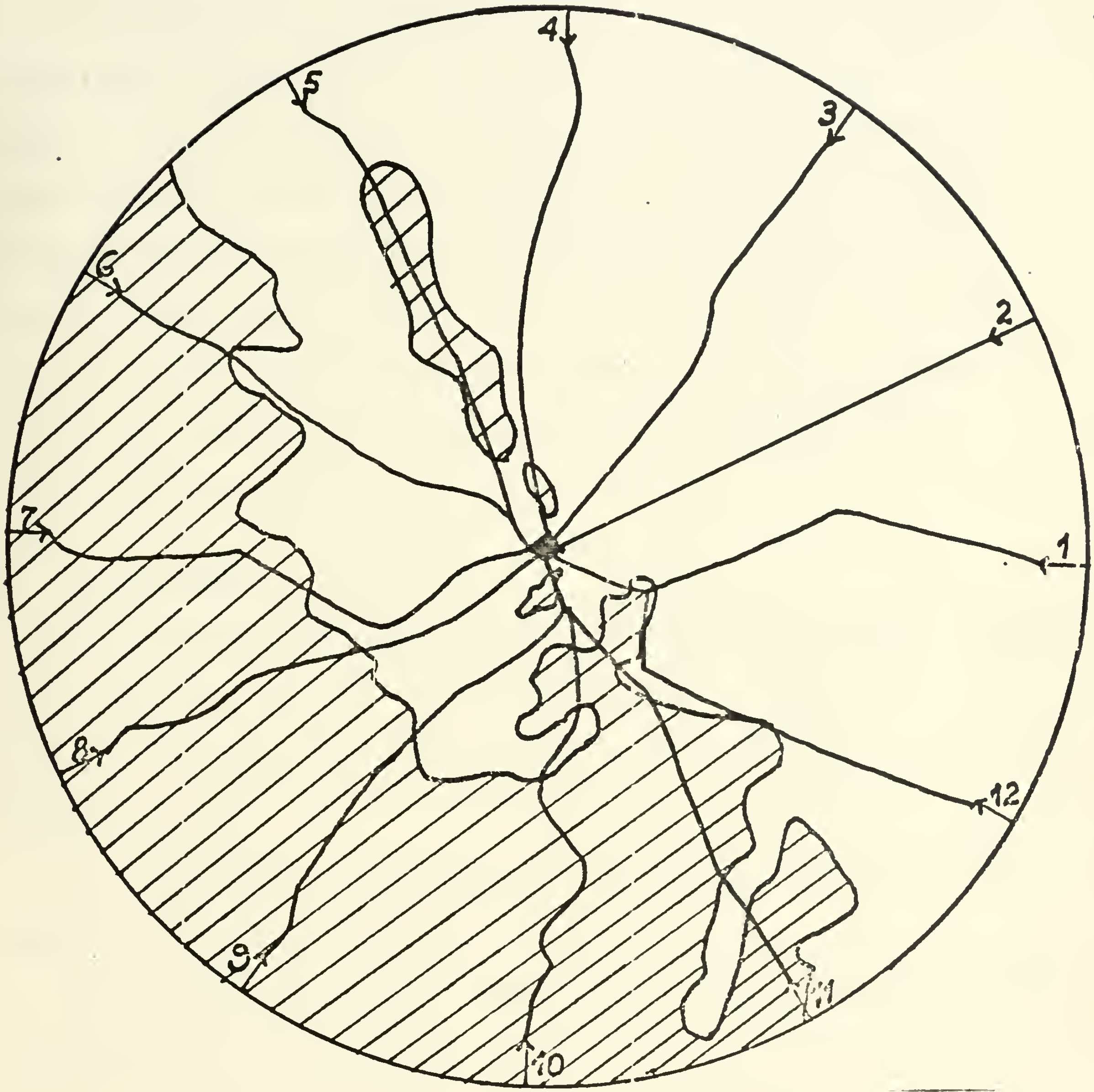
5. Each group should be considered as a separate entity. There is no interaction between groups.

6. Effort should be made to keep the infiltration route within 90° of direct approach unless the terrain prohibits this approach.

7. All indicated man-made structures on the map should be ignored with the exception of roads, bridges, and railroad tracks.

The intrusion routes selected are shown in Figure 3. These routes were digitized using the previously explained X-Y grid system and are an input to the program.

As previously explained, the movements of an intruder group are simulated in the model by discrete moves from one 100 meter square to the next along their programmed route. A check for detection is made after each move. Although



Shaded areas indicate broken terrain

Figure 3. The Preselected Infiltration Routes.

there is no continuous chance for detection throughout the route of the intruder, movement time, direction and velocity are computed based on the gradient of the terrain and the vegetation. These values influence the probabilities of detection of the ground surveillance radars and the night observation devices. This method of checking for detections after discrete movements and modification of detection probabilities based on the parameters of the move appears tenable for the purpose of the study. No better method suggested itself during study of models constructed to handle similar problems.

D. ENVIRONMENT

The environment assumed for the model has a major impact on the results obtained in a study such as this. For the purposes of this study the environmental conditions are assumed to be:

1. Night with light or no cloud cover, one to three quarters moon and no fog or haze.

2. No percipitation. Rain is quite detrimental to both visual and radar systems.

3. Light to no wind. Wind caused vegetation movements degrades the efficiency of the doppler radar systems.

E. SENSOR PLACEMENT

In order to obtain unbiased placements of the sensor systems in accordance with each of the specified doctrines the aid of another U.S. Army officer was requested. It was

desired that this officer have a general knowledge of base defense problems, a realization of the line-of-sight constraints imposed by dominating terrain and no knowledge of pre-selected intruder routes. A contemporary, an experienced Field Artillery officer and student at the Naval Postgraduate School, was selected to place the systems. He was supplied with a map of the area of operations which contained indications of the base location and the five kilometer radius base defense area. He was also supplied with eight blank overlays and a statement of instructions which outlined the general base defense problem, the sensor systems available for employment, and the eight test doctrines of sensor deployment (Appendix A). System performance values were supplied along with specific constraints on sensor locations. The officer was requested to locate the sensor systems in accordance with each of the doctrines and the requirements for base defense. The placement of the systems was noted on a separate overlay for each doctrine.

The locations of each of the devices was then digitized using the X-Y grid system and became an input to the applicable simulation run.

F. DETECTION CRITERIA

In order to inject additional realism into the model, a decision rule was developed for declaration of a detection. This rule as incorporated in the model is that two indicated detections of any intruder group within a base-to-target

range of 500 meters by any combination of individual devices constitute a formal detection. For example, if Ground Surveillance Radar Number 1 detects Intruder Group 1 at a range from the base of 1850 meters and later a detection of Intruder Group 1 is indicated from Sensor String Number 7 at a range of 1375 meters, then a formal detection is declared, the movement of the intruder group is terminated, the applicable facts are noted, and the next intruder group begins its advance.

This decision rule was included in the model to provide for such existing system problems as:

1. The high false alarm rate of unattended ground sensors.

2. The clutter problem often associated with vegetation movements which exists with doppler operating ground surveillance radars.

3. The strain-caused hallucinary effects often noted with devices requiring the human eye for night detection.

The actual decision rule that should be used to consider the above problems in a model such as this is a matter of some discussion. It appears, however, that the two detection, 500 meter rule provides the realism required for the purposes of this study. The proper decision rule to use is a portion of the command and control procedures associated with an integrated sensor system such as that described in this study. Because the question of optimal command and control procedures is a complex one, it is felt that the

resolution of this problem should be the focus of a study devoted entirely to this subject.

In the next chapter, the methods used to construct the model using the assumptions and rationale described will be discussed. The necessity for thorough consideration of the assumptions about a situation should become apparent.

IV. MODEL FORMULATION

Having acquired a simplification of reality by the assumptions described in Chapter III, one may now describe the scenario in which the doctrines will be tested by constructing a model of the base defense problem. This model, composed of several submodels, describes by use of mathematical relationships the actions and reactions occurring within the base defense area and ultimately produces resultant answers to the questions: Has an intruder been detected? If a detection has been made, what was the range at which the intruder was detected and which devices were responsible for this detection? The following paragraphs describe the construction of the model used in this study.

A. SCENARIO

The study used a specific base defense problem as a reference from which the various alternative doctrines could be evaluated. The selection of the actual physical site for the problem was described earlier in the discussion of terrain selection. As a part of the base defense, the sensing devices of an integrated sensor system are deployed around the base in order to detect intrusion of the base defense area by the enemy. The devices are employed in accordance with each specific doctrine.

The threat of enemy infiltration exists randomly throughout the base defense area with possible infiltration routes

limited only by natural terrain barriers. This means that the particular deployment of the sensor systems must be directed against an enemy intrusion from any direction tempered only by knowledge of existing terrain barriers. In the simulation, twelve enemy intruder groups are moved towards the base camp one at a time, over preselected infiltration routes. The different doctrines are compared in terms of the success realized by the particular deployment of the sensors against all infiltrating groups.

B. DETECTIONS

The success or failure of a particular detection device in a given situation is a matter of the capabilities of the system tempered by chance. To model the results of a sensor operating against various threats requires that a variety of factors be considered and accounted for in the model. The sensor systems considered in this study are of two general types. The ground surveillance radar and the night observation device are line sensors, while the unattended ground sensor could be characterized as a point sensor.

To model a line sensor requires consideration of the direction in which the sensor is aimed, the maximum effective range of the device, the line-of-sight requirement, sensitivity to the target area environment, sensitivity to target speed, and reduction in the detecting capability of the device as the range to the target increases. Also of

considerable importance is the basic probability of detection when using the device; that is, how many times out of a certain number of chances will a given target be detected with the device? All of these factors, when applicable, have been considered in modeling the ground surveillance radars and the night observation devices in this study.

As was stated in Chapter III, the basic probability of detection utilizing the ground surveillance radar is considered to be 0.90. This means that nine detections out of ten chances could be expected when utilizing this device in optimum conditions. The model constructed for the radars establishes this basic probability and then proceeds to reduce it in accordance with the vegetation in the target area and the time the target is available in the search area of the radar. In the simulation, Monte Carlo methods are used to determine if a detection has occurred. Of course, before the target can be considered for detection, it must be within the search area, within the maximum range, and within the line-of-sight of the radar. The target must, in addition, exceed the minimum radial velocity threshold of the radar.

Modeling of the night observation device in the study is in many respects identical to the radar problem. In fact, it will be seen in Chapter V that these devices share many portions of the programmed model. Besides the differences in maximum effective ranges and sector coverage noted in Chapter III, the visual devices differ in detection

capability from the radars in the required reduction in probability of detection as the range to the target exceeds 400 meters and the lack of requirement for minimum radial speeds of the target.

A point type sensor does not require the complexity of modeling that the line types do, but still, representing realistic detection activity presented a problem. The major effort in modeling the detections of the unattended ground sensors lay in the necessity of representing a small (40 meter radius) area of detecting region within a problem which utilized a fairly large (100 meter) increment of area measurement. This was accomplished by confining the sensor area of influence to the grid square in which it was located and utilizing the detection probability computed in Chapter III.

Randomization of actual detections with the night observation devices and the unattended ground sensors is accomplished in a manner identical with the radar model.

C. INTERVISIBILITY

The most tedious portion of the model concerns the continuous line-of-sight determinations for the line sensors. Without the aid of a computer this facet of the model would negate the ability to simulate a realistic situation since manual intervisibility checks are both time-consuming and tedious. Intervisibility determination was reduced to a computer compatable algorithm. After it has been

established that the target is within the search sector and within range of the sensor, this coded algorithm is used to determine if the target is within line-of-sight of a particular line sensor. The algorithm utilizes basic trigonometry and the elevation characteristics of the base defense area to determine if the intruder group being considered is within the line-of-sight of a particular device. The vertical angle between the device and the target location is computed and then the algorithm checks intermediate elevations by a series of incremented steps to determine if the basic vertical angle is exceeded. If no intermediate vertical angle exceeds the basic angle, the target is considered to be within the line-of-sight of the device.

Results of the intervisibility check determine whether the detection models of the line sensors will be utilized.

D. MOVEMENT

The movement of the intruder groups within the area is accomplished by discretely relocating the group from one grid square to the next in accordance with the preselected infiltration routes. The groups are considered in the problem sequentially - one through twelve - with each group's movement simulated from entry to completion (detection or successful infiltration) prior to consideration of the next group. Therefore, at no time will more than one intruder group be within the base defense area at any one time.

The movement of the intruder groups described above involves constant bookkeeping so that the location of the intruder group being considered is always known. The detection models of the line sensors, however, require information about actual movements of the intruder groups; that is, the distance covered, the average speed, and the time required in moving from the previous grid square to the grid square in which the group is located. In order to furnish this information, a movement model has been constructed.

The movement model enables the computation of the distance traveled by the group during the move by determining if the group moved to a contiguous square (a distance of 100 meters) or to a diagonally contiguous square (a distance of 141.1 meters). Using night travel speed for open terrain from military sources [5] and reducing this speed in accordance with the slope and vegetation characteristics of the particular terrain being traversed, an average speed of movement and the time required for the move are computed.

Finally, the radial velocity of the intruder group with respect to the particular device being considered is computed from the change in target-to-device range and the time of movement.

E. INTERRELATIONSHIP OF THE MODELS

The models discussed in this chapter describe the movements of the intruder groups within the base defense area

and the detection determinations which take place after each of an intruder group's discrete moves. A general outline of the models' use during each move would appear helpful in understanding how the situation has been simulated.

The location of the intruder group being considered is changed to the next location in accordance with the pre-selected infiltration routes. A check is made to determine if the group is within the scan sector and maximum range of a line sensor. If the group is located within the detection region of a line sensor, an intervisibility check is made to determine line-of-sight from the device to the group's location. If the group is within line-of-sight of the line sensor, the appropriate (radar or visual) detection model is used to determine whether a detection has been made. The movement model is used to furnish required information to the line sensor detection model. If a detection is made, a check of the two detection, five-hundred meter rule is required to determine if a formal detection has been made.

Upon completing the use of the line sensor models, the point sensor (unattended ground sensor) model is used to determine if the group has been detected by this type sensor. Again, the decision rule is used for determination of a formal detection.

Examination of various deployment doctrine alternatives using computer simulation was necessary because of the many intervisibility and detection checks necessary to adequately test each doctrine in the environment and against the

infiltration threat prescribed. The following chapter describes in detail the computer program which was written utilizing the ideas described in this chapter.

V. DESCRIPTION OF THE PROGRAM

This chapter contains the description of the computer simulation program based on the base defense model. The program was written in G-level Fortran IV and incorporates several built-in functions available in the standard IBM scientific programming package. A copy of the program is appended to this study.

The general logic of the program is shown in Figure 4. This diagram shows the relationships among the major components of the program. Each of these major components will be described in detail in the sections that follow.

The program as it presently exists requires 109,668 bytes of storage space during the execution phase and required twenty seconds to compile and approximately seventy-three seconds for each twenty-five iteration run utilizing the IBM 360/67 system at the Naval Postgraduate School.

A. THE MAIN PROGRAM

The very simple logic of the main program is shown in Figure 5. This portion of the program serves as the overall control of the simulation. During the initial execution all data enters the assigned storage. This data consists of the following:

1. Elevation Data

Stored in array ELEV, a 100 by 100 element matrix, the elevation data consists of 10,000 elevation readings of the

1. Start
2. Read Data
3. Iteration begins
4. Move Intruder Groups 1 - 12 sequentially.
5. Call the intervisibility routine. If target is in scan, in range, and in line-of-sight of a radar Go To 6. If target is in scan, in range, and in line-of-sight of a visual device Go To 7. If neither, or when completed Go To 8.
6. Radar detection routine. Call movement routine for movement parameters. Compute detection probability. Draw a random number. If a detection is made call detection routine. If no detection or when completed return to 5.
7. Visual detection routine. Call movement routine for movement parameters. Compute detection probability. Draw a random number. If a detection is made, call detection routine. If no detection or when completed return to 5.
8. If a detection has been signaled by the detection routine Go To next intruder and return to 4. If not, Go To 9.

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9. Call the sensor detection routine. If intruder is in range of an UGS, check for detection. If detected call detection routine. If no detection or when completed, Go To 10.
10. If a detection has been signaled by the detection routine go to next intruder and return to 4. If not, Go To 11.
11. If last move of intruder, Go To 12. Otherwise, return to 4.
12. If last intruder, Go to 13. Otherwise, Go To 4.
13. If last iteration, Go To 4. Otherwise, Go To 3.
14. STOP

Figure 4. General Program Flow.

1. Start

2. Store Elevation Data.

3. Store Vegetation Data.

4. Store Intruder Route Data.

5. Store Observation Device Location.

6. Store Observation Device Center Scan Orientations.

7. Store UGS Locations.

8. Move Intruder Group (1-12) to the next 100 meter square of his route.

9. Call Intervisibility Routine.

10. If there has been a formal detection, Go To 14. If not, proceed.

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A

11. Call the Sensor Detection Routine.

12. If there has been a form 1 detection, Go To 14. If not, proceed.

13. If not the last move for this group, Go To 8. Otherwise proceed.

14. If not the last group, designate next Intruder Group and Go To 8. Otherwise proceed.

15. If not the last iteration, designate Intruder Group 1 and Go To 8. Otherwise proceed.

16. STOP

Figure 5. The Main Program.

form XXXX., where XXXX is a four digit number representing the average elevation to the nearest ten feet of the particular 100 meter square. Information is retrieved from this array utilizing a statement such as BASEL = ELEV (Y,X), where Y and X represent the coordinates of the desired 100 meter square reading up to Y then right to X.

2. Vegetation Data

Information about the prevalent vegetation characteristics of each 100 meter square is stored in array ZVEG, also a 100 by 100 matrix. The vegetation data consists of 10,000 coded vegetation characteristics in accordance with the format described in Chapter II and of the form X, where X is an integer between one and four inclusive. Vegetation information concerning a particular 100 meter square can be obtained with a statement such as ZZ = ZVEG (Y,X), where Y and X are obtained as above.

3. Intruder Route Data

The data stored in arrays INT1 through INT12 is a digital representation of the route each of the intruder groups followed from the group's entry point to the base camp. Each of these arrays is an N by 2 matrix where N represents the total number of 100 meter squares traversed by the intruder group throughout the infiltration route. Coordinates for a particular location of an intruder group are retrieved as follows:

Desiring the coordinates of the 26^{th} square traversed by the sixth intruder, retrieve X and Y coordinates with these statements;

X = INT6 (26,1) ,

Y = INT6 (26,2) .

4. Number of Squares Traversed

The number of squares traversed by each intruder group - the N referred to above in paragraph 3 - is stored in array NNN(12), a vector of twelve elements. This information is required to control the cycling of the computer program.

5. Coordinates of the Observation Devices

The locations of the ground surveillance radars and the night observation devices during a specific simulation are stored in arrays OBSX and OBSY. These are seven-element vectors with the information ordered such that Elements One through Three correspond to radars one through three and Elements Four through Seven correspond to visual devices one through four. To obtain the location of the second night observation device for example, the following statements are used:

X = OBSX (5), Y = OBSY (5).

6. Scan Orientation

The orientation of each observation device is established by storing the center scan orientation of the devices in array SCAN, a seven element vector. The orientation of the radars and the visual devices are ordered in

the same manner as in the OBSX and OBSY arrays above. The values in the SCAN array represent the center scan of each device to the nearest tenth degree reading counterclockwise from east. For example, 90.0 represents a northern orientation and 180.0 a western orientation.

7. Unattended Ground Sensor Locations

The locations of the unattended ground sensors during a specific simulation are stored in arrays OST1 through OST10. The location of the three remote sensors of each sensor string may be obtained from these arrays in the following manner:

Desiring the location of the first sensor in sensor string number 7, retrieve the X and Y coordinates of this sensor with these statements;

X = OST7 (1,1) ,

Y = OST7 (1,2) .

In addition to inputing the data for the particular simulation, the main program controls the movement of the intruder groups during the program run. Normally the intruder groups are moved sequentially through their routes and checks are made for detection by ground surveillance radars, night observation devices, and unattended ground sensors after each individual movement. However, if an indication is received from the detection subroutine of a formal detection, the intruder group being moved by the main program is terminated and the next group's movement is started. Intrusions by the twelve intruder groups are replicated twenty-five times before program termination.

Since the major purpose of this study was to demonstrate a technique for comparing doctrines, twenty-five replications of the simulated problem appeared to be adequate. While requiring less than two minutes per simulation run, twenty-five replications nonetheless provide results which can be used to demonstrate a method of analysis.

B. THE INTERVISIBILITY SUBROUTINE

An outline of the intervisibility subroutine named INVIS is shown in Figure 6. This routine is used to decide if an intruder group has moved into an area that is within the scan, within the maximum range, and within line-of-sight of a ground surveillance radar or a night observation device. If all these conditions are met, then the radar detection subroutine or the visual detection subroutine are called.

The first action occurring within the intervisibility model is a determination of an intruder's presence within the scan sector of any of the observation devices. To accomplish this, the angle from each device to the intruder's location is computed and then, for each device, a check is made to see if the angle value falls within the following upper and lower limits:

SCANPLUS = Center scan orientation of the device plus one half the scan sector,

SCANMINUS = Center scan orientation of the device minus one half the scan sector,

where the scan sector is equal to 110° for the ground surveillance radars and 90° for the night observation devices.

1. INVIS called from Main Program.

2. Check GSR 1 - 3 and NOD 1 - 4 sectors to see if intruder is within scan of the observation device.

3. If not in sector, Go To 4. If intruder is in sector, Go To 5.

4. If this is last device, return to Main Program. Otherwise, designate next device and Go To 2.

5. Compute range from target to observation device. If not in range of device, Go To 4. Otherwise, Go To 6.

A

A

6. Compute vertical angle and check for line-of-sight. If target is not visible from device, Go To 4. Otherwise, Go To 7.

7. If device is a radar, Go to 8. Otherwise, Go To 9.

8. Call Radar Detection Routine. Upon return of control Go To 4.

9. Call Visual Detection Routine. Upon return of control Go To 4.

Figure 6. The Intervisibility Subroutine (INVIS).

Fairly detailed logic is necessary to insure proper coverage of the case where a sector includes 0°.

A small subroutine called COORD is used during this process to convert radian answers to degrees and to insure proper quadrant location

If after movement, an intruder group is within the assigned sector of a ground surveillance radar or a night observation device, the intervisibility routine computes the range from the target to the observing device. If the group is within the 3200 meters of a radar or 1600 meters of a visual device, the model begins the line-of-sight determination.

The logic used for the line-of-sight determination may be explained by an example. Consider that the observation device is located in the center of a circle and the intruder is located on the circumference as shown in Figure 7. The method used to check for intervisibility is as follows:

1. From the angle previously computed determine which <u>stepping case</u> to use. If the angle lies between 315° and 45° ($315° < \theta \leq 45°$), use Case 1; if $45° < \theta \leq 135°$, use Case 2; if $135 < \theta \leq 225°$, use Case 3; if $225° < \theta \leq 315°$, use Case 4. The stepping case used dictates the direction and grid component (X or Y) used to step from the observation device to the target location while checking for line-of-sight.

2. Retrieve the elevation of the observing device and the target based on their locations by using the inputed elevation data. Compute the vertical angle from the observing device to the target location.

3. Now begin a series of steps from the observation device location towards the target location in 100 meter increments along the:

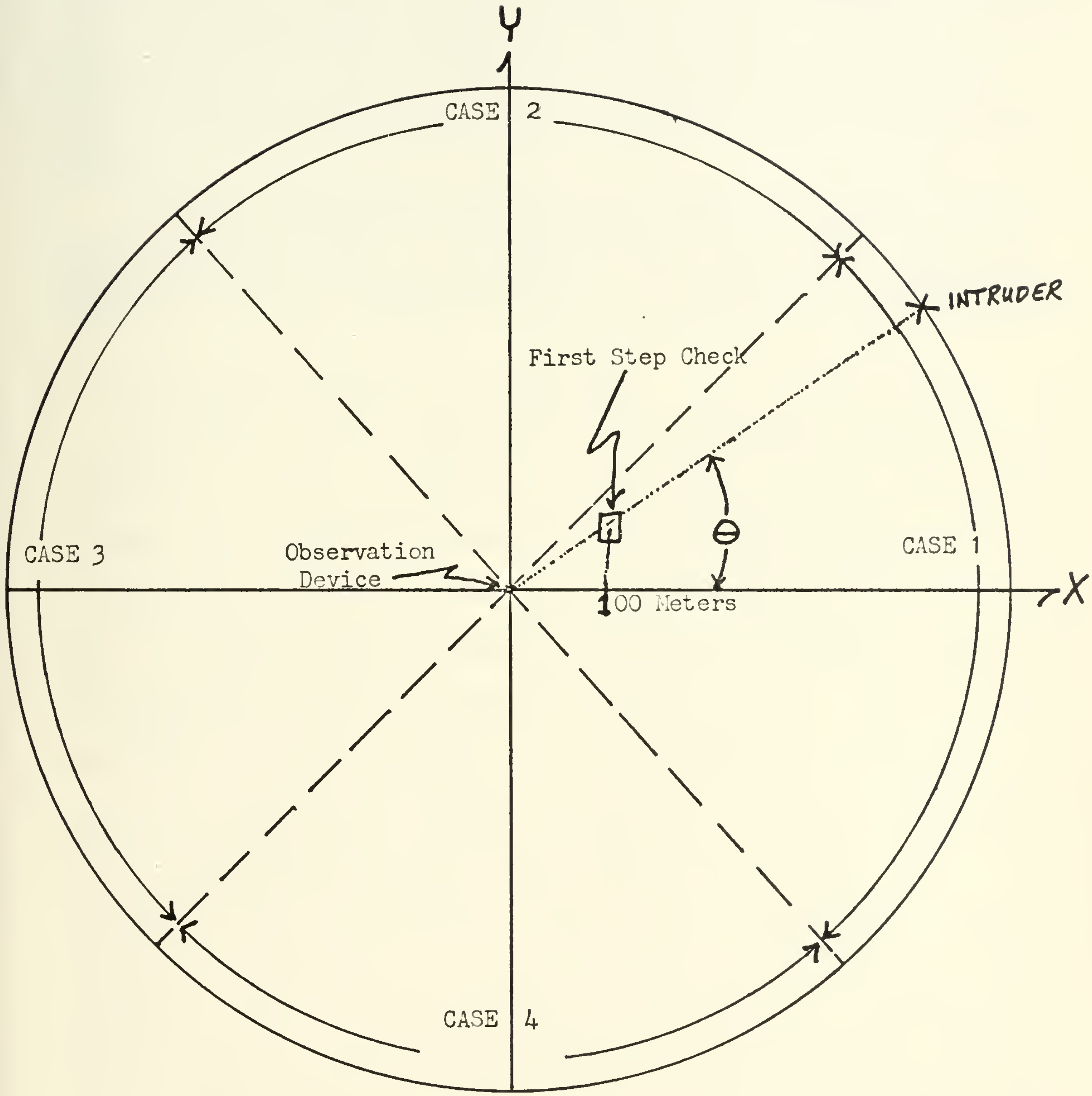


Figure 7. The Intervisibility Diagram.

Positive X direction for Case 1
Positive Y direction for Case 2
Negative X direction for Case 3
Negative Y direction for Case 4.

Compute the location of the nearest 100 meter square using the sum of the steps and the angle. Check the vertical angle from the observation device to this square. If while stepping towards the target any vertical angle is greater than the basic vertical angle, the target is not visible from the device and control is transferred back to the early portion of the program for scan checks of the remaining devices.

4. If no intermediate vertical angle is greater during the stepping process, the target is in the line-of-sight of the device and control is transferred to the radar detection subroutine or the visual detection subroutine as appropriate.

C. THE RADAR DETECTION SUBROUTINE

The basic logic used in the radar detection subroutine (RATECT) is shown in Figure 8. Here, it is first determined whether the target has penetrated beyond the minimum range of the ground surveillance radars (400 meters). If it has not, a basic detection probability of .90 is established. The movement subroutine (MOVE) is then called. From it is received required information on the target's radial velocity (rate of speed directly towards a point) with respect to the radar and the time the target is available for detection (see paragraph E, below for a description of the movement subroutine). If the target's radial velocity with respect to the radar is less than one kilometer per hour, then in accordance with the assumed limitations of the radar no detection is possible. However, if the radial velocity of the target is within detection limits, data about the vegetation characteristics of the target area will be retrieved from computer storage and the radar detection

1. Called from the intervisibility subroutine. A target is available to a specified GSR. Go To 2.

2. If the target is closer than 400 meters return to INVIS. Otherwise Go To 3.

3. Set Radar Detection probability to 0.90. Go To 4.

4. Call the Movement Subroutine for target's radial velocity and time available. Go To 5.

5. If radial velocity is less than 1 Km/Hr, return control to INVIS. Otherwise Go To 6.

6. Determine vegetation in target area and adjust Radar Detection Probability if required. Go To 7.

A

A

7. Adjust Radar Detection Probability for time the target is available. Go to 8.

8. Draw a random number. Go To 9.

9. If the random number is less than the adjusted Radar Detection Probability, Go To 10. Otherwise Go To 11.

10. Call the Detection Subroutine. Upon return of control, Go To 11.

11. Return control to the Intervisibility Subroutine .

Figure 8. The Radar Detection Subroutine (RATECT).

probability will be adjusted in consonance with the assumed foliage penetration characteristics of the radar.

Since it is assumed that one minute is required to search each 400 meters to 3200 meters, it takes the radar seven minutes to cover its entire area of responsibility. Therefore, if the target availability time received from the movement subroutine is less than seven minutes, the radar probability of detection is proportionally reduced if the target availability time is less than seven minutes. The actual radar detection probability for any given target availability is computed as follows:

$$\text{Radar Detection Probability} = (.90)\ (\text{Vegetation Factor})\ [\text{Min}\ (\text{Target Availability Time}, 7)/7]$$

$$\text{where the Vegetation Factor} = \begin{cases} 1.0 \text{ for Code 1 (Open terrain)} \\ 0.6 \text{ for Code 2 (Lightly wooded)} \\ 0.2 \text{ for Code 3 (Heavily wooded)} \\ 0.5 \text{ for Code 4 (Water)} \end{cases}$$

Finally, a random number is drawn and compared to the adjusted radar probability of detection. If a simulated detection occurs, this fact is passed to the detection subroutine.

D. THE VISUAL DETECTION SUBROUTINE

The basic logic used in the visual detection subroutine (VITECT) is depicted in Figure 9. This routine is used to control the detections made by night observation devices after it has been determined by the intervisibility sub-routine that a target is located within the maximum range,

1. Called from the Intervisibility Subroutine. A target is available to a specified NOD. Go To 2.

2. Set NOD detection Probability to 0.90. Go To 3.

3. If the target is closer than 400 meters, Go To 4. Otherwise adjust NOD detection probability for range and Go To 4.

4. Call the Movement Subroutine for target's time available. Go To 5.

5. If target time available is 5 minutes or greater, Go To 6. Otherwise adjust NOD detection probability for time available and Go To 6.

A

A

6. Determine vegetation in target area and adjust NOD detection probability if required. Go To 7.

7. Draw a random number. Go To 8.

8. If the random number is less than the adjusted NOD detection probability, Go To 9. Otherwise Go To 10.

9. Call the Detection Subroutine. Upon return of control, Go To 10.

10. Return control to the Intervisibility Subroutine.

Figure 9. The Visual Detection Subroutine (VITECT)

the assigned sector of responsibility, and the line-of-sight of a specific visual device.

A basic visual detection probability is initially established within this model. If the target-to-observer range is in excess of 400 meters, the visual detection probability is reduced in accordance with the assumptions by multiplying it by the ratio: 400 to target-to-observer range.

Since the visual device has a field of view of only 9°, it is assumed that a full sweep of the 90° area of responsibility requires some five minutes. The movement routine is called to obtain the target availability time and if this availability time is less than five minutes, the visual probability of detection is reduced by multiplying it by target availability time divided by five.

The vegetation characteristics of the target area are retrieved from storage and the detection probability is adjusted in consonance with the assumed foliage penetration capability of the visual device. The actual detection probability for any given available target is computed as follows:

Visual Detection Probability = (0.90) [400/Max (Range, 400)] [Min (Target Availability Time,5)/5] (Vegetation Factor),

$$\text{where the Vegetation Factor} = \begin{cases} 1.0 \text{ for Code 1 (Open Terrain)} \\ 0.8 \text{ for Code 2 (Lightly Wooded)} \\ 0.4 \text{ for Code 3 (Heavily Wooded)} \\ 0.5 \text{ for Code 4 (Water)} \end{cases}$$

Finally, a random number is drawn and compared to the adjusted visual probability of detection. If a simulated detection occurs, this fact is passed to the detection subroutine.

E. THE MOVEMENT SUBROUTINE

The basic logic used in the movement subroutine (MOVE) is shown in Figure 10. This subroutine computes information relative to the movement of the intruder group which is used by the radar and visual detection routines.

Using the intruder's present location (from the calling program) and his previous location (from stored route data), the model computes the distance traveled by the intruder during this move. Because of the discrete nature of intruder movements within the model, the distance traveled must be either 100 meters (movement to a directly contiguous square) or 141.4 meters (movement to a diagonally contiguous square). Using the elevations of the present and previous intruder locations, the average absolute slope traversed by the intruder group is calculated. The base velocity of three kilometers per hour assumed for all intruder groups is then adjusted in the following manner:

slope $\leq$ .05, Base velocity unchanged
.05 < slope $\leq$ .20, Base velocity reduced by 10%
.20 < slope $\leq$ .40, Base velocity reduced by 30%
.40 < slope , Base Velocity reduced by 50%.

The vegetation characteristic of the target area is retrieved from the stored data and the intruder velocity is adjusted as follows:

1. Called from Radar Detection or Visual Detection Subroutine. Go To 2.

2. Retrieve intruder's previous location. Go To 3.

3. Calculate the distance traveled this move. Go To 4.

4. Set Base Velocity equal to 3 Km/Hr. Go To 5.

5. Calculate gradient of move. Adjust velocity for gradient. Go To 6.

A

A

6. Retrieve vegetation characteristics. Adjust velocity for vegetation. Go To 7.

7. Compute time required for this move. Go To 8.

8. Calculate the radial velocity of this move towards the observer. Go To 9.

9. Return required information to the calling program.

Figure 10. The Movement Subroutine (MOVE).

Code 1 vegetation, no reduction
Code 2 vegetation, velocity reduced by 10%
Code 3 vegetation, velocity reduced by 30%
Code 4 vegetation, velocity reduced by 50%.

Utilizing the adjusted speed of intruder movement and the computed distance of the move, the time required for the intruder to complete this move is calculated. This time becomes the target availability time used by the radar and the visual detection routines.

In order to calculate the radial velocity of the intruder towards the observation device the change in the target-to-observer range as a result of the current move is calculated. The radial velocity is then computed by multiplying the adjusted intruder velocity by the ratio of change in range to distance traveled.

Upon completion of the above calculations required information along with program control is returned to the calling program.

F. THE SENSOR DETECTION ROUTINE

The basic logic used in the unattended ground sensor detection model (SENTEC) is outlined in Figure 11. This subroutine is called by the main program after each move made by an intruder group.

In order to save time during a computer run of the simulation, the first check made by this subroutine is an approximate determination of the intruder's proximity to any sensor string. To accomplish this, it is determined

1. Called from the Main Program. Go To 2.

2. Compare the intruder's coordinates with coordinates of center sensor of Strings 1 through 10. Go To 3.

3. If intruder is not located within 400 meters in X & Y direction of center sensor, Go To 4. Otherwise, Go To 5.

4. If this is last string to be checked, return control to the Main Program. Otherwise, Go To 2.

A

A

5. Compare intruder's location to location of each sensor in string. If intruder is in the same grid square as one of the sensors, Go To 6. Otherwise, Go To 4.

6. Draw a random number. If random number is less than sensor probability of detection, Go To 7. Otherwise, Go To 4.

7. Call detection subroutine. Upon return of control, Go To 4.

Figure 11. The Sensor Detection Routine (SENTEC)

if the intruder is within 400 meters in both the X and Y direction of the center sensor of the string. This check is made sequentially for all ten sensor strings each time an intruder group moves. If an intruder is within 400 meters of the center sensor of the string, a more detailed check of the intruder's proximity to the sensors of the string is made.

To accomplish the detailed check, the intruder's location coordinates are compared to the location coordinates of each of the three sensors of the string. In accordance with the assumptions relating to unattended ground sensor detections, the coordinates of the intruder must exactly match those of a remote sensor in order for there to be a chance of detection. If the coordinates match, indicating that the intruder is located in a 100 meter square protected by a sensor, a random number is drawn. If the random number is less than or equal to 0.4526 (the detection probability derived in the assumption section), a detection is declared and control is passed to the Detection Subroutine.

G. THE DECISION SUBROUTINE

In accordance with the rationale described in Chapter III, an arbitrary decision rule requiring two indicated detections by any combination of devices within a base-to-target range of 500 meters was adopted. To represent this decision process, the decision subroutine (DETECT) is called by any of the detection routines (RATECT, VITECT, or SENTEC) when an individual detection occurs.

Upon receiving the information relating to the detection, this decision subroutine stores the base-to-target range of the detection and the identification of the specific detecting device. This detection information is then compared with each previous detection of this intruder group. If no combination of detections satisfies the decision rule, control is returned to the calling subroutine. If, however, a combination of individual detections satisfies the two detection, 500 meter decision rule, a formal detection is declared. The base-to-target range at which the second detection occurred and the identity of the specific devices furnishing the required two detections are printed. The main program is signaled that a formal detection has been made of the current intruder group. This group is deleted from the program and infiltration is initiated on the next intruder route.

The program described in this chapter was used to simulate the base defense problem. The results obtained using data from eight different deployments are presented and discussed in the following chapter.

VI. AN INVESTIGATION OF SELECTED DEPLOYMENT DOCTRINES

This chapter contains the results of computer simulation of the base defense problem using various doctrines for deployment of the sensor systems. An attempt to compare the merits of the deployment schemes is made using game theory as an analytic tool.

In order to compare the results from each deployment scheme it seems reasonable to select a measure or measures of effectiveness which view the base defense problem from the standpoint of the base commander. What results would he desire from an integrated sensor system?

First, the system should have a high probability of detecting infiltrators before they reach a position from which they can attack the base camp. Therefore, the first measure of effectiveness would appear to be the percentage of infiltration groups detected.

Because the infiltrators might launch a standoff attack against the base camp, the base commander's second consideration might well be the detection of infiltration groups at the greatest possible range. Therefore, a second measure of effectiveness of a deployment scheme could be the range at which an intruder group is detected, given that such a detection occurs.

The relative importance of these two measures of effectiveness should normally depend on the tactical situation

which confronts a specific base commander. Such factors as terrain characteristics, base camp type, and enemy capabilities should vary the importance of these two measures.

The following sections contain a description of the doctrines used to deploy the sensor systems tested in this study, a graphical representation of the deployment of individual sensors in each simulation series, and the results of twenty-five iterations of twelve simulated infiltrations against each deployed system. The results obtained from each of the schemes tested are first presented individually with only general analysis of specific results - that is, obvious strengths or weaknesses. A comparative analysis of the deployments utilizing the two measures of effectiveness described above is presented at the end of the chapter.

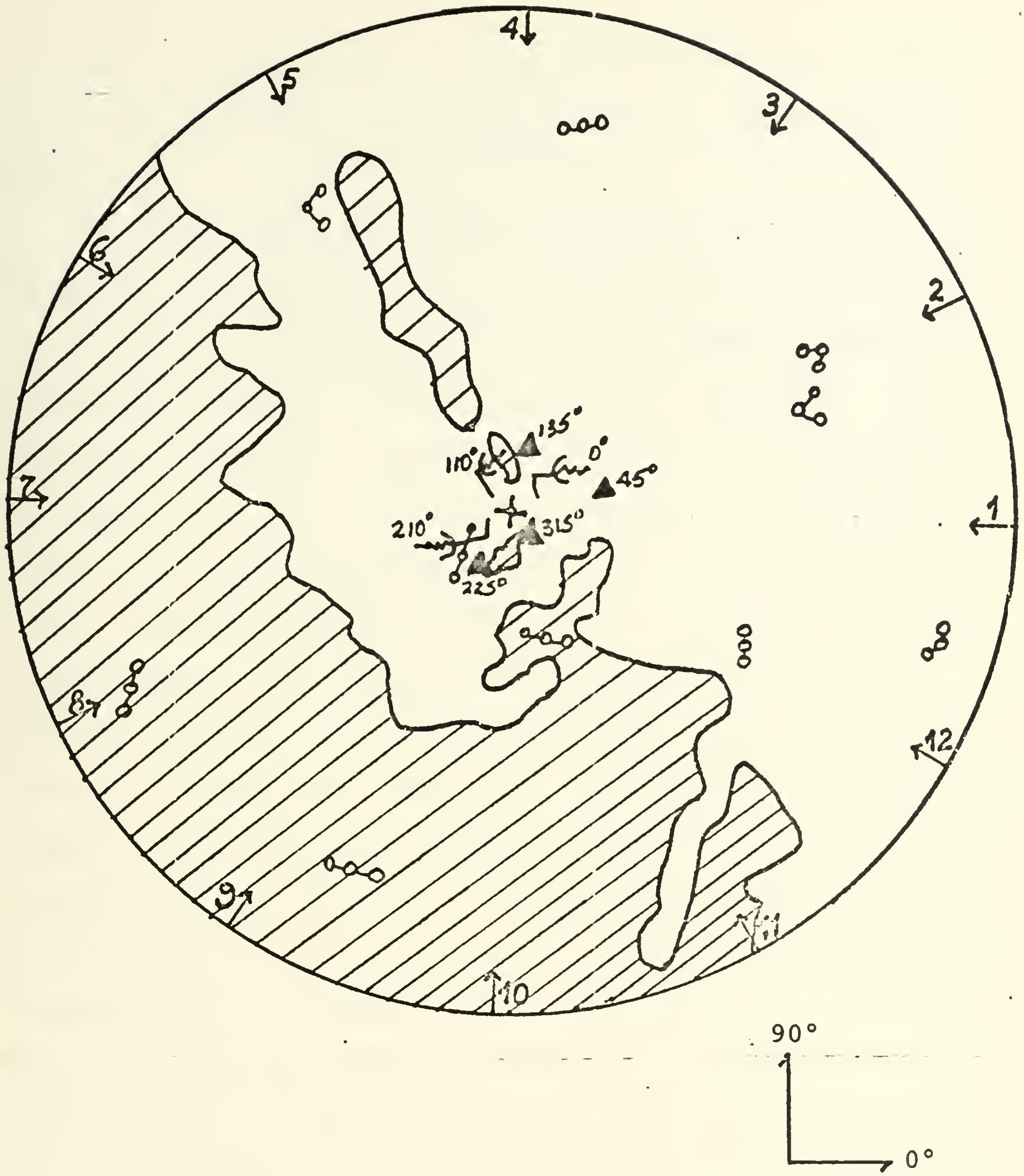
A. SIMULATION SERIES 1.

The officer deploying the sensors for Simulation Series 1 was furnished the following doctrine statement to use as guidance.

> "Radars and visual devices are [to be] used as a primary surveillance means of the area beyond the base perimeter. Isolated detection devices are [to be] placed at or near areas masked from line-of-sight for early detection of intruders as they approach the base."

This statement of sensor deployment doctrine was drawn from a U.S. Army Field Manual entitled Base Defense.

The approximate locations of the sensors deployed under this guidance are shown in Figure 12. The coordinate location of each device deployed in each simulation series may



....Ground Surveillance Radar } Center Scan Orientation Indicated
....Night Observation Device
....Three Element Sensor String

Figure 12. Approximate Location of Devices in Simulation Series 1.

be found in Appendix B. A summary of the detection results using this particular sensor deployment is given below in Table I.

In reading this table and the tables that follow in this chapter an explanation of the various columns would appear to be helpful. The upper portion of the table summarizes the history of each of the twelve intruder groups. (The specific route used by each intruder group was shown earlier in Figure 3.) The third column indicates the number of times each group was formally (using the two detection, 500 meter decision rule) detected out of twenty-five infiltration attempts. The fourth column indicates the average base-to-target range at which the group was detected given that it was detected. The fifth column shows the average range of detection when undetected intruders are assigned a detection range of zero. These summary values will be useful later in comparing results of deployment schemes. Because of the two-decection decision rule, the total number of detections registered is twice the sum of the third column, e.g., in Table I the sum of the third column is 144 but since two detections are required to obtain a formal detection, there were in fact 288 detections recorded in this simulation.

The second part of the table shows the relative contribution of each type of sensor system to the results obtained in this simulation series. Although each individual detection acquired by a specific sensor is available in the

TABLE I

DETECTION RESULTS OF SIMULATION SERIES 1

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	15	1507.4	904.4
2	25	24	2162.1	2075.6
3	25	0	0.0	0.0
4	25	4	806.2	129.0
5	25	0	0.0	0.0
6	25	0	0.0	0.0
7	25	25	2630.8	2630.8
9	25	8	2279.9	729.6
10	25	18	744.7	536.2
11	25	3	223.6	26.8
12	25	23	1947.0	1791.3
Total	300	144		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	288.	214	74.3
Visual	288.	69	24.0
Remote Sensor	288.	5	1.7

output from the computer simulation, only those detections contributing to a formal detection are reflected in the summary figures in the tables.

Of interest in the results above is the fact that intruder Groups 3, 5, and 6, all traveling in relatively open terrain, were never detected. This could be because line - of - sight problems in the placement of the radars and visual devices which were targeted against that region of their infiltrations precluded better results against these groups. Although their routes lay in fairly open terrain, terrain masks near the base camp could have interfered with the line sensors.

It can be noted that the unattended (remote) ground sensors were relatively ineffective in this deployment scheme. It would appear that the wide dispersal of the sensor strings suggested by this doctrine will be most successful when the deployer of the devices correctly guesses the routes to be used by the infiltrators. This was evidently not the case in this particular scheme.

In judging the deployment of the sensors in this simulatio series it can be seen that only 144 formal detections were obtained out of 300 chances for a detection rate of 48%. Detecting less than half of the infiltrators would probably not be considered an unqualified success even in a simulated base defense problem.

B. SIMULATION SERIES 2

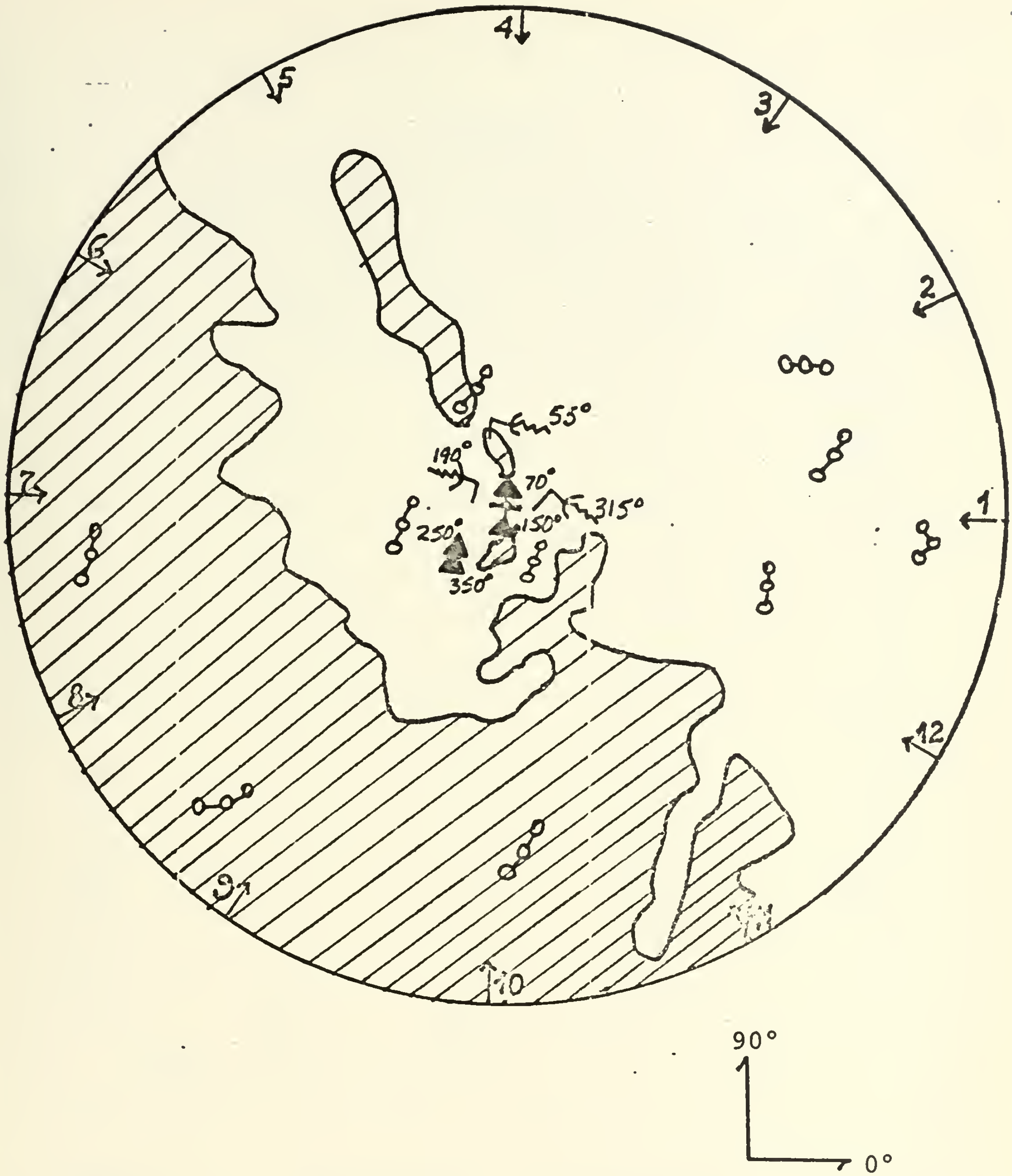
In Simulation Series 2, the officer deploying the sensors was furnished the following doctrine statement to use as guidance.

> "Radars and visual devices are [to be] used as a primary surveillance means. Unattended ground sensors should be utilized to cover likely avenues of approach for early warning regardless of line-of-sight considerations."

This doctrine statement varies from the first in that unattended ground sensor deployment is not required to be limited to areas masked from line-of-sight, although they are still to be used for early warning.

The approximate locations of the sensors deployed under this guidance are shown in Figure 13. A summary of the detection results using this particular sensor deployment is given below in Table II.

Note that although the number of detections has increased significantly (from 144 to 175), Groups 5 and 6 and additionally Group 4 have escaped detection. A study of the summary results in Table II and the deployment diagram for this simulation series suggests that the night observation devices may have been placed in areas masked from most of the infiltration routes, especially those groups whose routes lay in the second quadrant. Although the doctrinal guidance for deployment of the line sensors in Simulation Series 2 did not vary from that used in Simulation Series 1, the deployment of the radars and the visual devices was changed. It appears that the deployment of the radars used in this series



....Ground Surveillance Radar
....Night Observation Device

Center Scan Orientation Indicated

....Three Element Sensor String

Figure 13. Approximate Location of Devices in Simulation Series 2.

TABLE II

DETECTION RESULTS OF SIMULATION SERIES 2

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	16	1703.0	1089.9
2	25	21	1823.9	1532.1
3	25	21	1828.4	1535.8
4	25	0	0.0	0.0
5	25	0	0.0	0.0
6	25	0	0.0	0.0
7	25	24	2613.3	2508.8
8	25	25	2736.7	2736.7
9	25	9	2013.2	724.8
10	25	25	1524.9	1524.9
11	25	12	1944.1	933.2
12	25	22	2004.6	1764.0
Total	300	175		

Device	Available	Detections	Detections
Radar	350.	322	92.0
Visual	350.	13	3.7
Remote Sensor	350.	15	4.3

was markedly superior to that used in the first series while the deployment of the visual devices appears to have been inferior. It can be assumed from a study of the deployment diagram that the radars have been placed in a manner to increase their line-of-sight capability in their areas of search.

The detection percentage for deployment of the sensor systems in Simulation Series 2 was 58%. The more liberal guidelines for deploying the unattended ground sensors has increased the effectiveness of this sensor system over that of the first simulation series. However, again, it can be conjectured that the wide dispersal of these devices will not result in many detections unless the deploying officer has knowledge of likely infiltration routes.

C. SIMULATION SERIES 3

The officer deploying the sensors for Simulation Series 3 was furnished the following doctrine statement to use as guidance.

> "Radars should always be oriented only towards open terrain and overlapped in coverage if necessary. Visual devices and unattended ground sensors should be used to cover the areas not considered for radar coverage."

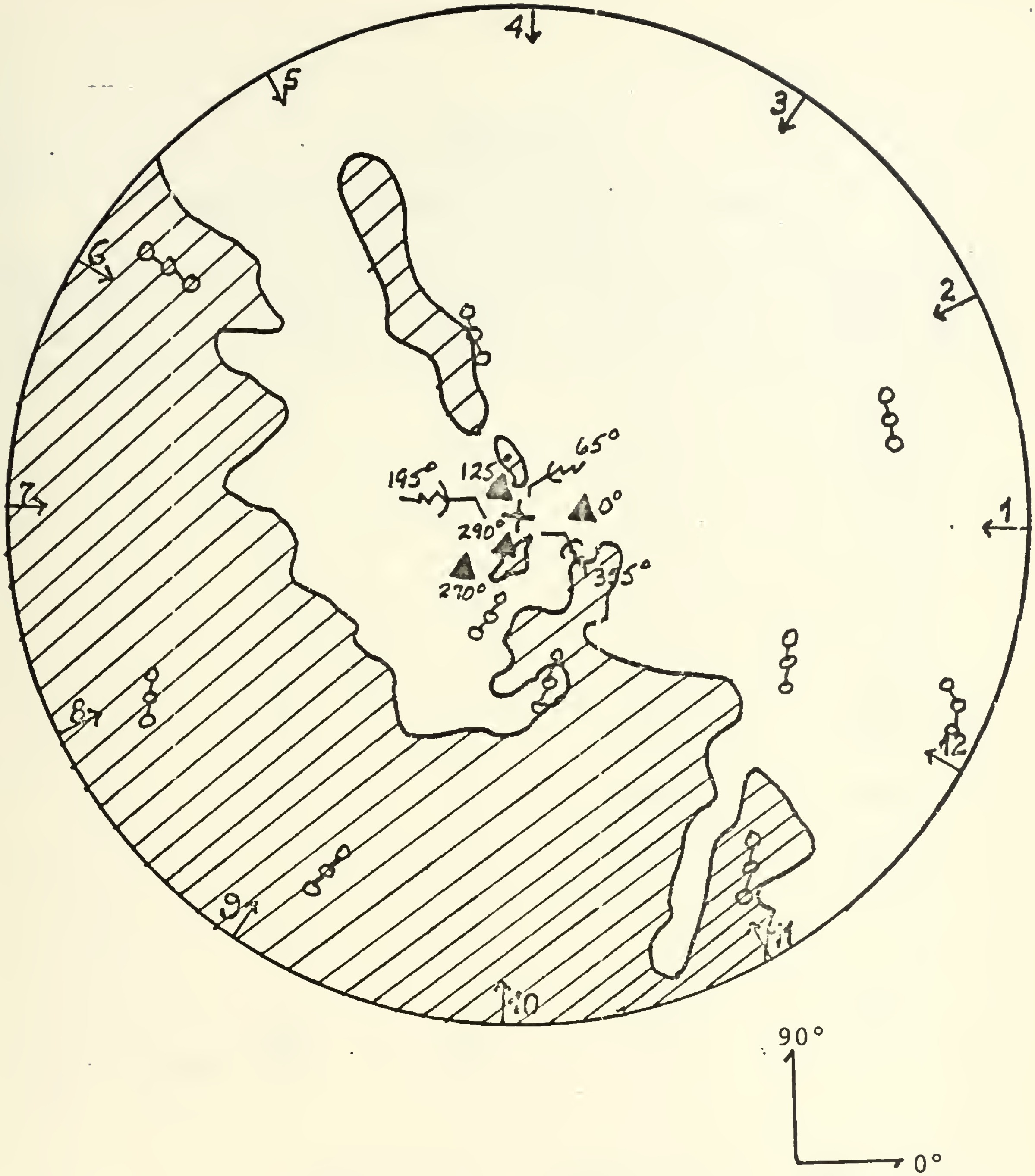
This doctrine statement is a radical departure from the first two considered in that the orientation of the ground surveillance radars is specifically directed towards only open terrain with the night observation devices and the unattended ground sensors used to cover those areas which were not considered open enough for radar use.

The approximate locations of the sensors employed under this guidance are shown in Figure 14. A summary of the detection results using this particular sensor deployment is given below in Table III.

Since it achieved only 136 detections out of 300 chances, the deployment of sensor systems in this series does not appear to have been very successful. The most striking value in Table III is the total detections acquired by the unattended ground sensors. It can be seen from the deployment diagram in Figure 14 that these sensors are again widely dispersed although this dispersal was not required specifically by the doctrine statement. These results appear to reinforce the conjecture that widely dispersed remote sensors will not be effective in a problem such as this unless the deploying officer has knowledge of likely infiltration routes.

Although the radar coverage was limited to open terrain by the doctrine statement, it can be noted from the diagram that only seventy degrees of the base defense circle are devoid of radar coverage. These areas contain major portions of the infiltration routes of the four intruder groups who had the most success in infiltrating - groups 4, 5, 10, and 11. This, again, points to the poor location of the visual devices which were required to cover these areas.

This deployment scheme resulting in a detection percentage of 45% was not successful.



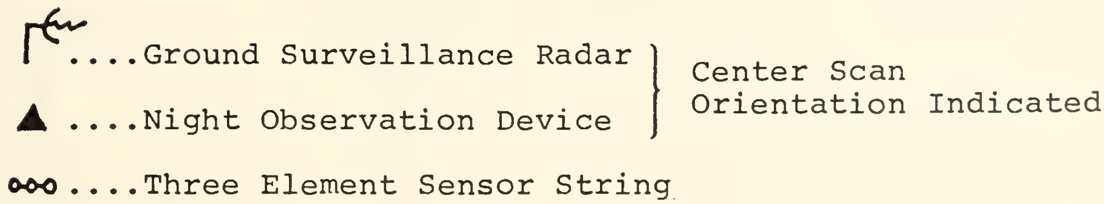


Figure 14. Approximate Location of Devices in Simulation Series 3.

TABLE III

DETECTION RESULTS OF SIMULATION SERIES 3

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	11	991.8	436.4
2	25	25	2249.6	2249.6
3	25	6	680.7	163.4
4	25	0	0.0	0.0
5	25	1	989.9	39.6
6	25	9	1109.7	399.5
7	25	25	2907.8	2907.8
8	25	25	2804.9	2804.9
9	25	11	1737.5	764.5
10	25	0	0.0	0.0
11	25	0	0.0	0.0
12	25	23	2002.4	1842.2
Total	300	136		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	272.	234	86.0
Visual	272.	38	14.0
Remote Sensor	272.	0	0.0

D. SIMULATION SERIES 4

The officer deploying the sensors for Simulation Series 4 was furnished the following doctrine statement.

> "Visual devices should always be oriented towards open terrain and overlapped in coverage if necessary. Radars and unattended ground sensors should be used to cover the areas not considered for visual coverage."

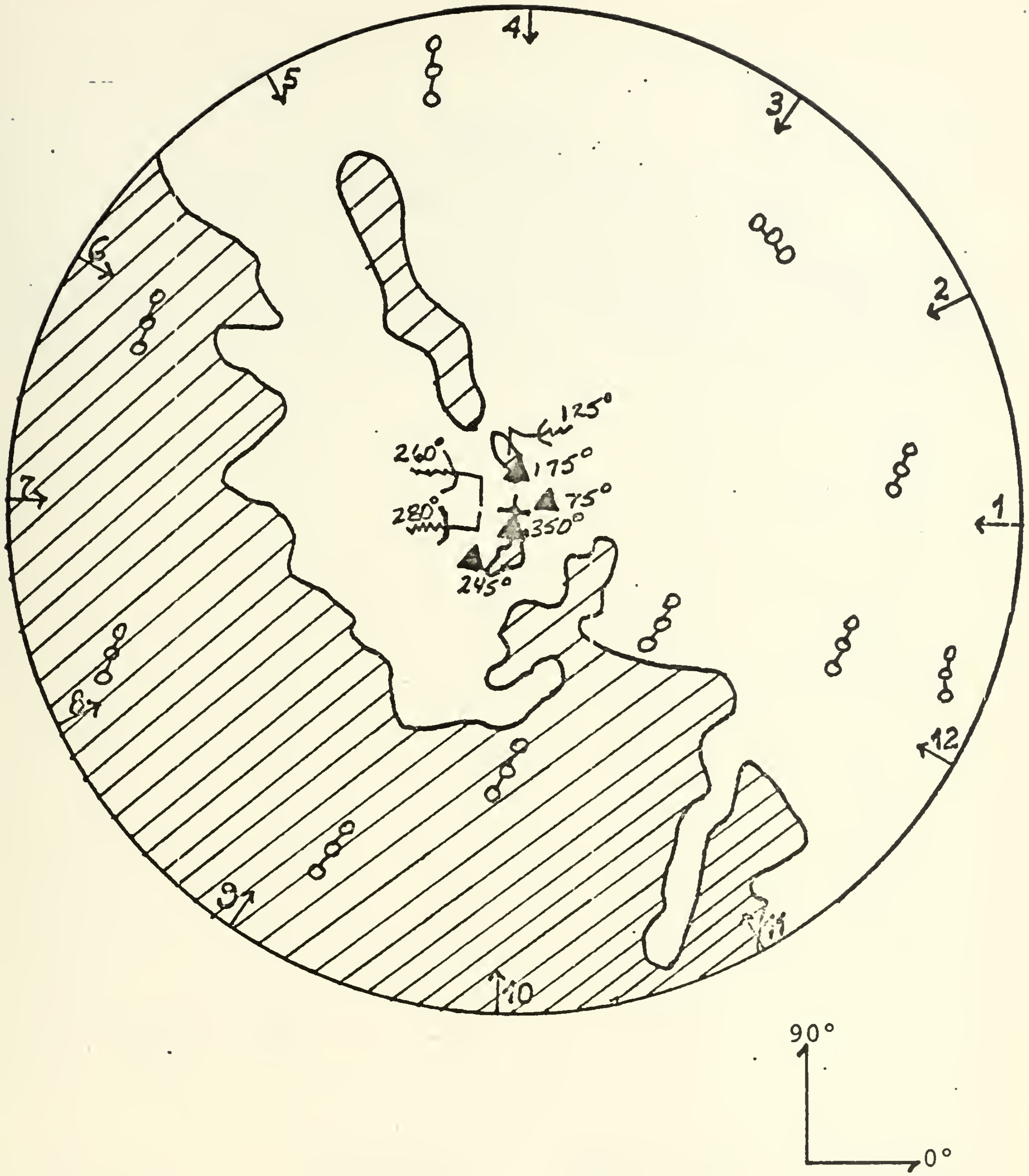
It should be noted that this doctrine statement is a reversal of the doctrine statement in Simulation Series 3, since the roles of the ground surveillance radars and the night observation devices have been interchanged.

The approximate locations of the sensors employed under this guidance are shown in Figure 15. A summary of the detection results using this particular sensor deployment is given below in Table IV.

The results of Simulation Series 4 are much the same overall as those obtained in Simulation Series 3 with only an increase of three detections for a total of 139 detections out of 300 chances. The unattended ground sensors were again widely dispersed and were again relatively ineffective.

It is interesting to note that the first four intruder groups, all with infiltration routes in the relatively open first and second quadrants, were never detected by the sensors deployed in the manner shown in Figure 15. It would appear that the visual devices oriented to 75° and 350° were masked by some prominent terrain features.

Also of interest is the fact that Groups 7, 8, 9 and 10 with infiltration routes in the rugged third quadrant, were



....Ground Surveillance Radar
....Night Observation Device
} Center Scan Orientation Indicated

....Three Element Sensor String

Figure 15. Approximate Location of Devices in Simulation Series 4.

TABLE IV

DETECTION RESULTS OF SIMULATION SERIES 4

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	0	0.0	0.0
2	25	0	0.0	0.0
3	25	0	0.0	0.0
4	25	0	0.0	0.0
5	25	7	200.0	56.0
6	25	17	864.8	588.1
7	25	11	1172.5	515.9
8	25	25	2797.4	2797.4
9	25	23	2118.4	1949.0
10	25	25	2095.8	2095.8
11	25	13	2604.4	1354.3
12	25	18	2182.8	1571.6
Total	300	139		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	278.	204	73.4
Visual	278.	71	25.5
Remote Sensor	278.	3	1.1

detected quite successfully. This seems to indicate that concentrated radar coverage as used in this deployment scheme will be quite successful in this problem regardless of the general characteristics of the terrain.

Although fairly successful in the broken terrain, the failures of this deployment scheme in the more open terrain and the low overall percentage of detections of 46% appear to mitigate against its use.

E. SIMULATION SERIES 5

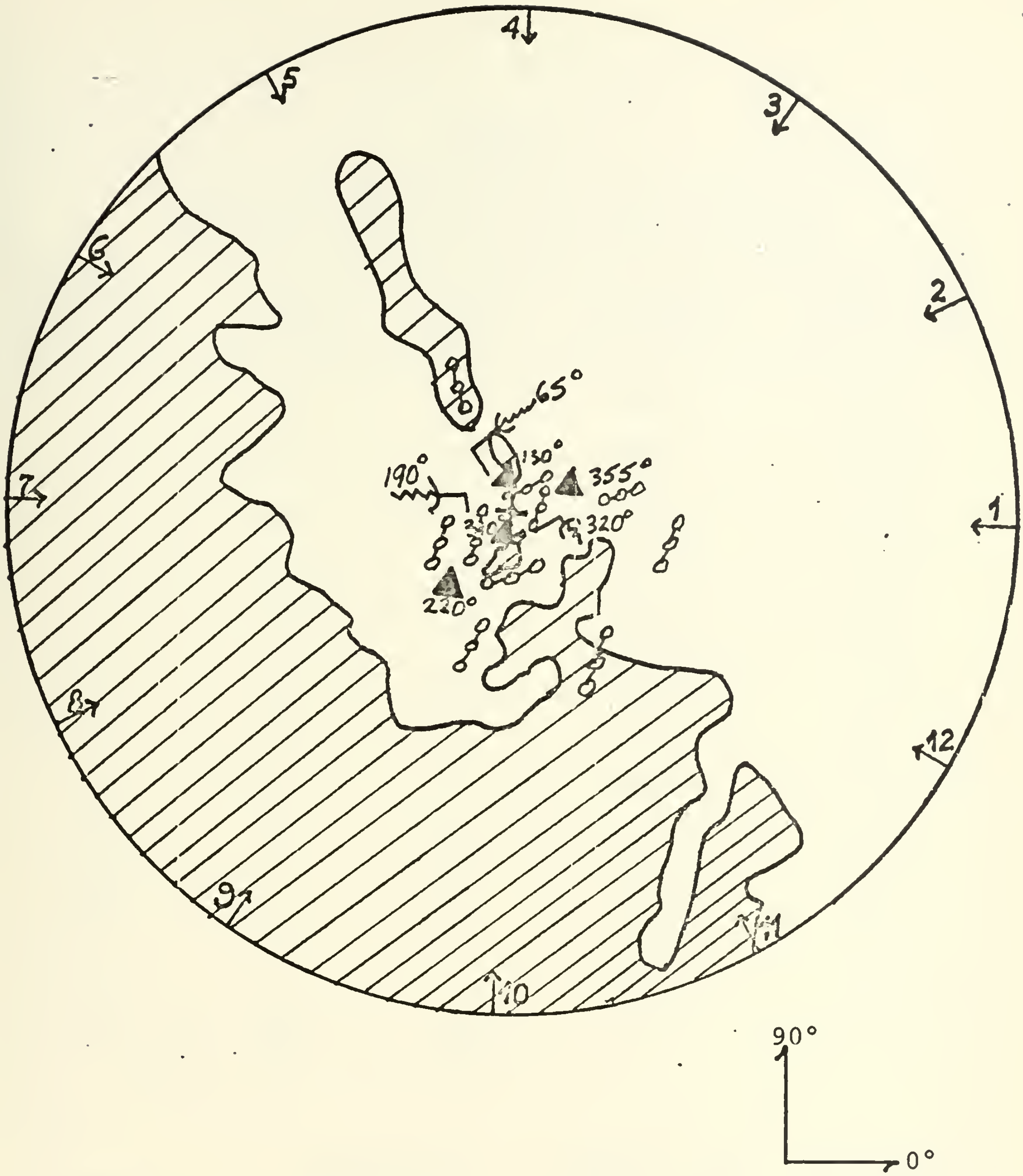
For Simulation Series 5, the guiding doctrine was:

> "Radars and visual devices are [to be] used as a primary surveillance means. Unattended ground sensors should be used near base camp to insure that no infiltration group penetrates the base itself."

This statement of doctrine is less detailed than others used in this study with only general location of the unattended ground sensors specified. The approximate locations of the sensors deployed in accordance with this doctrine statement are shown in Figure 16. The results obtained using this scheme of deployment are found in Table V below.

The results contained in Table V appear to indicate that the deployment scheme used in Simulation Series 5 is quite successful. Note that 230 detections were obtained out of 300 chances and every intruder group was detected at least once.

Especially noteworthy is the improved performance of the unattended ground sensors. Concentrating the coverage of



....Ground Surveillance Radar
....Night Observation Device
Center Scan Orientation Indicated

....Three Element Sensor String

Figure 16. Approximate Location of Devices in Simulation Series 5.

TABLE V

DETECTION RESULTS OF SIMULATION SERIES 5

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	20	1036.2	829.0
2	25	24	1802.2	1730.1
3	25	8	597.8	191.3
4	25	20	678.0	542.4
5	25	21	1300.8	1092.7
6	25	18	1269.8	914.3
7	25	25	2410.8	2410.8
8	25	25	2780.2	2780.2
9	25	12	1320.2	633.7
10	25	25	1382.1	1382.1
11	25	9	1869.6	673.1
12	25	23	1755.3	1614.8
Total	300	230		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	460.	297	64.6
Visual	460.	130	28.3
Remote Sensor	460.	33	7.2

these remote sensors near the base camp appears to improve their success.

In deploying the line sensors in accordance with the very general guidelines, the officer seems to have followed a symmetric rule. Almost all areas are covered by both the radars and the visual devices. This scheme appears to have been equally successful in the open and broken terrain.

With a detection percentage of almost 77% the deployment scheme in Simulation Series 5 appears to be successful.

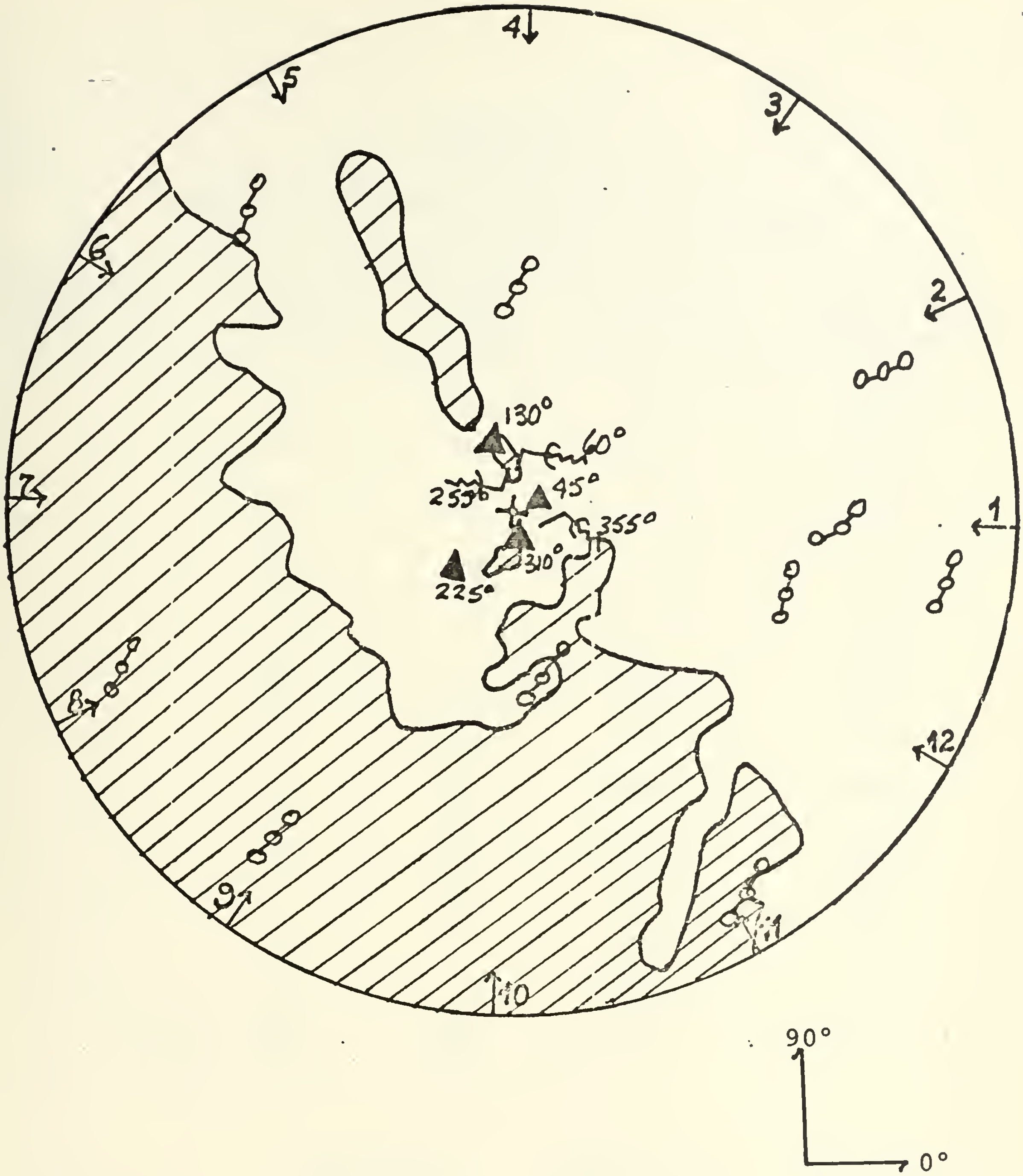
F. SIMULATION SERIES 6

Deployment guidance in Simulation Series 6 came from the following statement.

> "Radars should always be oriented towards only open terrain and overlapped in coverage if necessary. Visual devices should be oriented towards terrain not covered by the radars. Unattended ground sensors should be used to cover areas masked from line-of-sight for early detection of intruders."

This doctrine statement is a combination of that given in the doctrine statement for Simulation Series 3 for deployment of ground surveillance radars and night observation devices and that of Simulation Series 1 for deployment of unattended ground sensors. The sensors were deployed in approximately the manner shown in Figure 17. The results obtained utilizing the deployment scheme of Simulation Series 6 are shown in Table VI below.

The results of Simulation Series 6 are fairly impressive with 203 detections out of 300 chances. Only Intruder Groups 4, 5, and 11 avoided detection more than half the time.



....Ground Surveillance Radar } Center Scan Orientation Indicated

....Night Observation Device

....Three Element Sensor String

Figure 17. Approximate Location of Devices in Simulation Series 6.

TABLE VI

DETECTION RESULTS OF SIMULATION SERIES 6

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	20	1134.8	907.8
2	25	25	2355.3	2355.3
3	25	22	1513.2	1331.6
4	25	0	0.0	0.0
5	25	5	516.0	103.2
6	25	15	909.5	545.7
7	25	23	1729.1	1590.7
8	25	25	2419.0	2419.0
9	25	16	1793.7	1148.0
10	25	22	1382.3	1216.4
11	25	7	2692.6	753.9
12	25	23	2151.3	1979.2
Total	300	203		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	406.	342	84.2
Visual	406.	58	14.3
Remote Sensor	406.	6	1.5

There does not appear to be a noticeable difference in the success of the deployment scheme in relation to the characteristics of terrain used by the infiltrators.

Although the doctrine under which the line sensors were deployed in this simulation series was identical with that of Simulation Series 3, the more symmetric deployment in this series resulted in more successful results. The only area not covered by the radars is located in the second quadrant and is almost readily identifiable because of the lack of detection or low average detection ranges of the infiltration routes - 4, 5, and 6 - in this area.

The wide dispersal of the unattended ground sensors was again unsuccessful in this series.

The detection percentage of 67% resulting from the deployment scheme used in Simulation Series 6 can be termed moderately successful.

G. SIMULATION SERIES 7

The officer deploying the sensors for Simulation Series 7 was furnished the following doctrine statement to use as guidance.

> "Radars should always be oriented towards only open terrain and overlapped in coverage if necessary. Visual devices should be oriented towards terrain not covered by the radars. Unattended ground sensors should be used near base camp to insure that no infiltration group penetrates the base itself."

This doctrine statement is exactly the same as that used in Simulation Series 6 with the exception of the guidance for deploying the unattended ground sensors. With respect to

deployment of the unattended ground sensors the statement is identical to that used in Simulation Series 5. The approximate location of the sensors in Simulation Series 7 may be found in Figure 18. The detection results obtained using the deployment scheme of this simulation series are shown in Table VII below.

Like the results of Simulation Series 5 and Simulation Series 6, those of Series 7 are fairly impressive in terms of total detections - 199 out of a possible 300. The relative ineffectiveness of the night observation devices is evident. These devices were ineffective in Simulation Series 6 in which they were deployed utilizing the same doctrine as in this case.

The ground surveillance radars (again deployed almost symmetrically) were responsible for the bulk of the detections obtained in this series. A minor weakness in the second quadrant is again evident, but it is not so striking as in Simulation Series 6.

An unexpected result of this series was the performance of the ground surveillance radars. Although the doctrine for deployment of these sensors was identical to that of Simulation Series 5 in which these remote sensors enjoyed comparative success, only ten detections were obtained from this source in Series 7. A glance at the deployment diagram contained in Figure 18, however, shows that these sensors were not concentrated as tightly around the base camp as they were in Series 5.

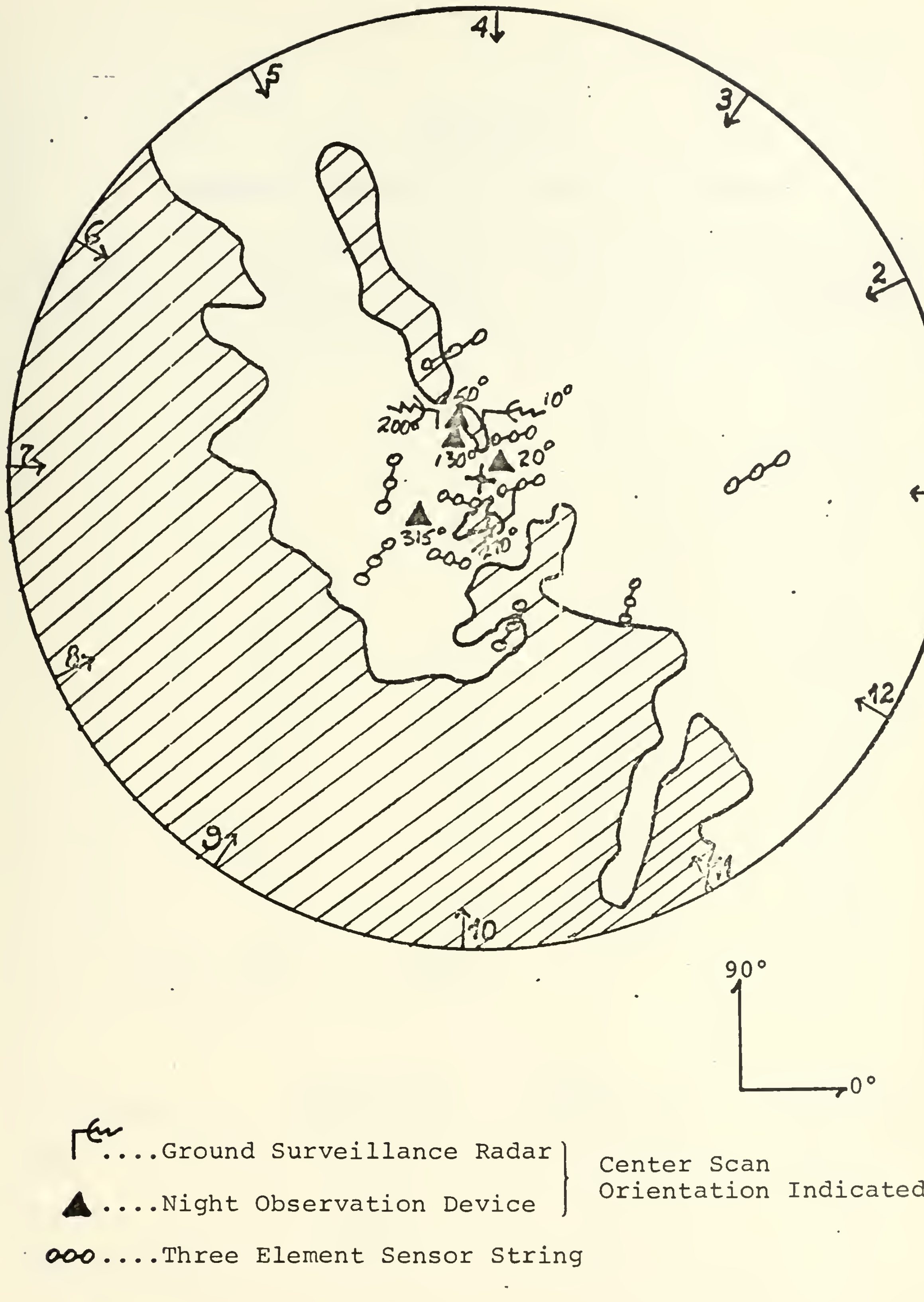


Figure 18. Approximate Location of Devices in Simulation Series 7.

TABLE VII

DETECTION RESULTS OF SIMULATION SERIES 7

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	15	2278.4	1367.0
2	25	19	1570.7	1193.7
3	25	22	1710.0	1504.8
4	25	0	0.0	0.0
5	25	4	920.7	147.3
6	25	22	1343.0	1181.8
7	25	25	2656.9	2656.9
8	25	25	2435.0	2435.0
9	25	25	1670.3	1670.3
10	25	24	1705.9	1637.7
11	25	5	2692.6	538.5
12	25	13	879.2	457.2
Total	300	199		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	398.	356	89.4
Visual	398.	32	8.0
Remote Sensor	398.	10	2.5

Simulation Series 7 with a detection percentage of 66% can be termed moderately successful.

H. SIMULATION SERIES 8

In the final simulation series, the following doctrine statement was used as guidance.

> "Radar coverage should never overlap. Visual device coverage should never overlap. Unattended ground sensors should be used to cover likely avenues of approach."

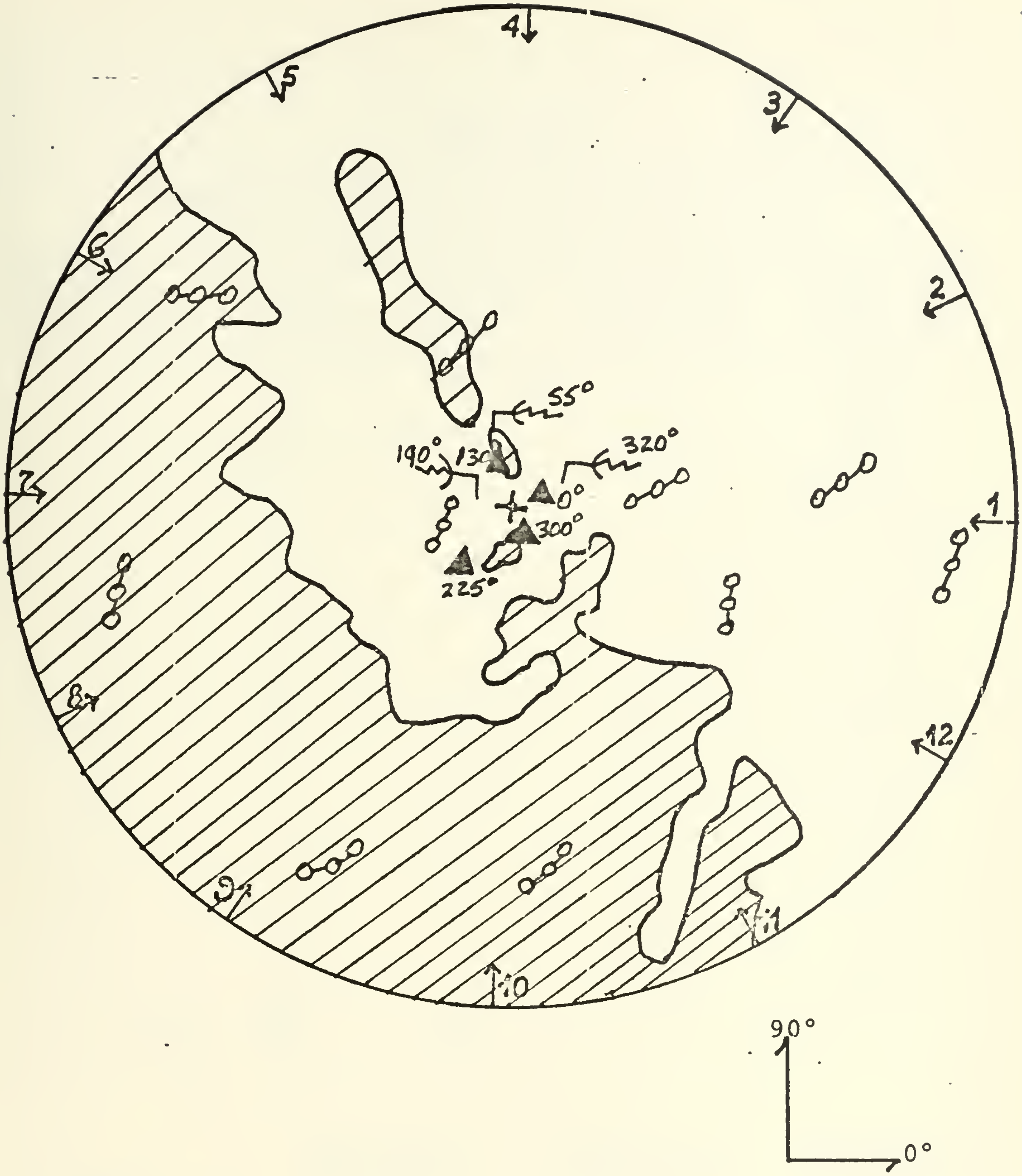
This was the least specific of the eight doctrine statements used in this study, but was still somewhat restrictive in respect to deployment of the ground surveillance radars and the night observation devices. The approximate locations of the sensors is shown in Figure 19. Results obtained in Simulation Series 8 are shown in Table VIII below.

The total number of detections obtained using the deployment scheme of Simulation Series 8 was 133 detections out of a possible 300. Four intruder groups were undetected in this series and three more were detected in less than half their intrusions. This deployment scheme showed lack of success in all the quadrants and in both open and broken terrain.

Only the ground surveillance radars, deployed symmetrically, enjoyed any success in this simulation series. The night observation devices were relatively ineffective.

Once again, the wide dispersal of the unattended ground sensors resulted in no success.

With a detection rate of only 44%, the deployment scheme used in Simulation Series 8 could be termed a failure.



....Ground Surveillance Radar
....Night Observation Device

Center Scan Orientation Indicated

ooo....Three Element Sensor String

Figure 19. Approximate Location of Devices in Simulation Series 8.

TABLE VIII

DETECTION RESULTS OF SIMULATION SERIES 8

Intruder Group Number	Times Available	Times Detected	Ave Range of Detection	Overall Range Detection
1	25	24	1707.5	1639.2
2	25	18	1825.2	1314.1
3	25	0	0.0	0.0
4	25	0	0.0	0.0
5	25	0	0.0	0.0
6	25	0	0.0	0.0
7	25	25	2565.0	2565.0
8	25	25	2851.7	2851.7
9	25	6	2402.7	576.6
10	25	6	2055.1	493.2
11	25	6	1637.8	393.1
12	25	23	1744.2	1604.7
Total	300	133		

Device	Detections Available	Number of Detections	Per Cent of Detections
Radar	266.	248	93.2
Visual	266.	18	6.8
Remote Sensor	266.	0	0.0

Results of Individual Analysis

Although concerned about the reasons for the various results obtained in each simulation series, a summary of the analysis of the individual results is limited to the following: total detections, percentage of detections, and the number of intruder groups undetected in twenty-five attempts.

The following table contains these summary totals.

TABLE IX

SUMMARY OF ANALYSIS OF INDIVIDUAL SIMULATION SERIES

Simulation Series	Total Detections	Percentage of Detections	Number of Groups Undetected
1	144	48%	3
2	175	58%	3
3	136	45%	3
4	139	46%	4
5	230	77%	-
6	203	67%	1
7	199	66%	1
8	133	44%	4

The examination of the results obtained in each simulation series was helpful in learning how systems performed in each case and it is meaningful to compare these results.

I. COMPARATIVE ANALYSIS OF THE TESTED DOCTRINES

In this section analysis of the results of the eight simulation series is performed in a comparative manner. Two methods of analysis, one using game theory and the other using decision theory, are used to compare three different summary results of the eight simulation series - detections, average detection range, and overall detection range.

Before beginning the comparative analysis, it would appear helpful to review the basic results obtained from the individual analysis of each series and the scenario used to simulate the base defense problem.

1. The Scenario

In analyzing the results of the simulations conducted in a comparative sense it is necessary to recall that all results are dependent on the scenario that was constructed in order to derive a model for the base defense problem.

The scenario that was used in this study required the deployment of a specified integrated sensor system in accordance with the guidance furnished in a doctrine statement. The infiltration threat used to test the deployment schemes was constant throughout the various simulations and consisted of twelve intruder groups utilizing preselected

infiltration routes which were roughly distributed uniformly throughout the base defense area. It was assumed that the infiltrator had a general knowledge of the sensor capability of the base but no knowledge of specific capabilities or locations of the individual devices.

2. Comparative Analysis Using Number of Detections and a Two-person, Zero Sum Game

In attempting to select the doctrine (or doctrines) which best fulfill the measures of effectiveness outlined above, an approach which was suggested seems both mathematically and esthetically satisfying. This approach utilizes the framework of basic game theory to cast the options available to the base commander and those available to the infiltrator into the form of a two-person, zero sum game. This formulation, often called a rectangular game, requires a choice among several options by the two participants in the game. These choices, made individually and without knowledge of the opponent's choice, define a payoff to one of the players based on the value of the cell designated by the choices made.

Considering first the results with number of detections obtained as the measure of effectiveness, number of detections obtained, the results of the computer simulation are arranged in the matrix that follows.

Doctrines \ Intruder Routes	1	2	3	4	5	6	7	8	9	10	11	12
1	15	24	0	4	0	0	24	25	8	18	3	23
2	16	21	21	0	0	0	24	25	9	25	12	22
3	11	25	6	0	1	9	25	25	11	0	0	23
4	0	0	0	0	7	17	11	25	23	25	13	18
5	20	24	8	20	21	18	25	25	12	25	9	23
6	20	25	22	0	5	15	23	25	12	25	9	23
7	15	19	22	0	4	22	25	25	25	24	5	13
8	24	18	0	0	0	0	25	25	6	6	6	23

The cell values represent the number of detections obtained using a particular doctrine in attempting twenty-five detections of a specific intruder. Since the cell values represent a "payoff" to the base commander, he will attempt to maximize the cell chosen, while the intruder will attempt to minimize the cell value and thereby his chance of detection. Although it is unlikely that the intruder would have such specific information available in choosing his route, it must be assumed that he will act rationally based on his knowledge of the terrain and his general knowledge of his opponent's detection system.

In selecting the optimum strategies for both players, it must be remembered that the base commander wishes to maximize his payoff (the cell values), while the intruder wishes to minimize it. By noting the minimum value in each row, and the maximum value in each column, a search is conducted

for a "saddle-point." This method is based on pessimism by both players, that is, they search for the worst they can do by choosing each strategy. If a point is found that is both the maximum value of its column and the minimum value of its row, then a saddlepoint is found and the game is solved. Unfortunately, in this case no saddlepoint exists.

Next, an attempt is made to eliminate doctrines and routes based on "dominance." This method makes use of the rationale that if any column or any row is clearly superior to another column or row from the standpoint of the player using it, it is "dominated" by the superior strategy. It can be noted that Row 1 is dominated by Row 5, that is, from the standpoint of the base commander, every payoff in Row 5 is greater or equal to that in Row 1. Therefore, Row 1 may be eliminated from consideration, since no matter what route the intruder chooses, the base commander can always do better by choosing Doctrine 5. Now Column 5 is dominated by Column 4, eliminating Column 5. Column 1 is dominated by Column 4, eliminating Column 1. Now Row 8 is dominated by Row 5, eliminating Row 8. Column 10 is dominated by Column 11; Column 8 is dominated by Column 9; Columns 2, 7, and 12 are dominated by Column 4, eliminating Columns 10, 8, 2, 7, and 12.

No more elimination by domination is possible and the reduced matrix appears below.

		Intruder Routes				
		3	4	6	9	11
Doctrines	2	21	0	0	9	12
	3	6	0	9	11	0
	4	0	0	17	23	13
	5	9	20	18	12	9
	6	22	0	15	16	7
	7	22	0	22	25	5

Because of the success of Doctrine Five against Route Four, it must be a candidate for the optimum doctrine. However, neglecting Route Four, Doctrine Seven appears clearly superior to the rest (although weak against Route Eleven). From these reasons Doctrines Five and Seven appear to be the best of the eight for satisfying the measure of number of detections. Although not a purpose of the study, a conclusion regarding the best routes for the intruder to use may be drawn. From examination of the matrix it appears that Routes 4 and 11 are the best for use by the intruder.

3. Comparative Analysis Using Number of Detections and Decision Theory

Before leaving the examination of the results of the different doctrines based on the number of detections obtained, an approach which does not require any assumption about the rationality of the opponent might be interesting. Such an approach assumes only that the specific route which will be selected by the infiltrator is unknown and no knowledge of a possible basis of selection of the route is

available to the base commander. Therefore, the probabilities associated with the route selection process will be considered to be equally likely, an assumption often called the Lagrange approach to the decision process under uncertainty.

The commander may also be interested in the number of detections he will forfeit by choosing a doctrine which does not provide the maximum number of detections of an intruder using a particular route. This method of decision analysis was proposed by Savage in 1951 and the amount lost by selecting the row in which the chosen column produced less than maximum payoff is called the regret.

The following analysis will make use of both of these decision methods. The base commander's regret will be calculated for each possible event (combination of doctrine and route). Instead of selecting the minimum of the maximum regrets associated with each doctrine as is normally done in the regret approach to decision making, the assumption of equally likely events will be used in this process. The sum of the base commander's forfeits for choosing each doctrine will be calculated over all possible intruder routes (within the scenario of this study).

Under this approach, the doctrine which minimizes this average of forfeits would be considered to be the best under the assumption of no knowledge of the route selection process.

Mathematically, this process can be written as follows for the i^{th} doctrine:

-- Sum of Forfeits = $\sum_{j\,(\text{columns})} [(\max_k a_{kj}) - a_{ij}]$

Doctrines	Intruder Routes 1	2	3	4	5	6	7	8	9	10	11	12	Average Forfeit
1	9	1	22	16	21	22	1	0	17	7	10	0	10.5
2	8	4	1	20	21	22	1	0	16	0	1	1	6.9
3	13	0	16	20	20	13	0	0	14	25	13	0	11.2
4	24	25	22	20	14	5	13	0	2	0	0	5	10.9
5	4	1	14	0	0	4	0	0	13	0	4	0	3.3
6	4	0	0	20	16	7	2	0	9	3	6	0	5.6
7	9	6	0	20	17	0	0	0	0	1	8	10	5.9
8	0	7	22	20	21	22	0	0	19	19	7	0	11.4

From the average forfeits it appears evident that Doctrine Five is superior to the other doctrines with respect to detections. In fact, since the forfeits can be interpreted as detections lost because of using a particular doctrine instead of the best doctrine for each route, it can be seen that use of Doctrine Five for all cases reduces the chance of detecting an entering intruder by only 40/300 or 13.4 percent of the chance of detecting with perfect information about the route selected by the intruder.

4. Comparative Analysis Using Average Detection Range and a Two-person, Zero Sum Game

A second measure of effectiveness proposed for the integrated sensor deployment problem was the range at which an intruder was detected, given that such a detection occurred.

In comparing the results of the simulations with this measure of effectiveness the same two analytic methods will be used.

The basic two-person, zero sum game matrix for this phase of the analysis is as follows (note the lack of a saddle-point).

Doctrines	Intruder Routes 1	2	3	4	5	6	7	8	9	10	11	12
1	1507	2162	0	806	0	0	2564	2631	2279	745	224	1947
2	1703	1823	1828	0	0	0	2613	2737	2013	1525	1944	2005
3	992	2250	681	0	990	1110	2908	2805	1737	0	0	2002
4	0	0	0	0	200	865	1172	2797	2118	2096	2604	2183
5	1036	1802	598	678	1301	1270	2411	2780	1320	1382	1870	1755
6	1135	2355	1513	0	516	909	1729	2419	1794	1382	2693	2151
7	2278	1571	1710	0	921	1343	2657	2435	1670	1705	2693	879
8	1707	1825	0	0	0	0	2565	2852	2403	2055	1638	1744

Using the dominance method again it is noted that Columns 1, 2, 7, 8, 9, and 12 are dominated by Column 4 which means the infiltrator will do better to choose Route 4 over any of the dominated routes no matter which doctrine is chosen. Row 8 is dominated by Row 4 and Row 6 is dominated by Row 7. The reduced matrix appears as follows.

Doctrines	Intruder Routes 3	4	5	6	10	11
1	0	806	0	0	745	224
2	1828	0	0	0	1525	1944
3	681	0	990	1110	0	0
4	0	0	200	865	2096	2604
5	598	678	1301	1270	1382	1870
7	1710	0	921	1343	1706	2693

Again, Doctrines 5 and 7 appear to be superior overall to the other doctrines.

5. Comparative Analysis Using Average Detection Range and Decision Theory

To use the concept of the commander's loss or forfeit the regret values are calculated as before and the following matrix is obtained.

Doctrines	Intruder Routes 1	2	3	4	5	6	7	8	9	10	11	12	Average Forfeit
1	771	193	1828	0	1301	1343	344	221	184	1351	2469	236	665.1
2	575	532	0	806	1301	1343	295	115	450	571	749	178	546.2
3	1286	105	1147	806	311	242	0	47	726	2096	2693	181	797.6
4	2278	2355	1828	806	1101	478	1736	55	345	0	89	0	917.6
5	1242	553	1230	128	0	73	497	72	1143	714	823	428	570.2
6	1143	0	315	806	785	434	1179	443	669	714	0	1304	537.5
7	0	784	118	806	380	0	251	417	793	390	0	1304	431.9
8	571	530	1828	806	1301	1343	343	0	0	41	1055	439	688.1

Here Doctrine Seven exhibits the lowest total forfeit, although the order of magnitude of the differences is small, Doctrine Six has the second lowest forfeit total - this doctrine also had the second lowest regret total when numbers of detections were considered.

6. Comparative Analysis Using Overall Average Detection Range and a Two-person, Zero Sum Game

In an attempt to resolve the problem of selecting the optimum doctrine using both measures of effectiveness a third criterion was examined. This was the overall average range of detection; so named because nondetection of a target was counted as a detection at zero range. Therefore, the averages reflect not only success in detecting the target at a long range, but also success in detecting the target at all. The game matrix containing this summary data as payoffs appears below.

	Intruder Routes											
Doctrines	1	2	3	4	5	6	7	8	9	10	11	12
1	904	2075	0	129	0	0	2462	2631	730	536	27	1791
2	1090	1532	1536	0	0	0	2509	2737	725	1525	933	1764
3	436	2250	163	0	40	399	2908	2805	764	0	0	1842
4	0	0	0	0	56	588	516	2797	1949	2096	1354	1572
5	829	1730	191	542	1093	914	2411	2780	634	1382	673	1615
6	908	2355	1332	0	103	546	1591	2419	1148	1216	754	1979
7	1367	1194	1505	0	147	1182	2657	2435	1670	1638	538	457
8	1639	1314	0	0	0	0	2565	2852	577	493	393	1605

Although the game matrix appears quite formidable, it can quickly be reduced by dominance to a two by two game matrix. Note first that Columns 1, 2, 7, 8, 9, 10, and 12 are dominated by Column 4. After their elimination Rows 1, 3, and 8 are dominated by Row 5. Eliminating these Rows, Columns 11, 6, and 5 are dominated by Column 4. Finally, Rows 6 and 7 are dominated by Row 2 leaving the two by two game matrix shown below.

		Intruder Routes 3	Intruder Routes 4
Doctrines	2	1536	0
	5	191	542

Using the methods described in basic game theory references [8], the following set of inequalities and equations is used to find the optimum strategies of the opponents and the expected payoff of the game.

Let X_2 represent the proportion of the time Doctrine 2 should be used and X_5 the proportion Doctrine 5 should be used. Similarly, Y_3 represents the proportion of the time Route 3 is used and Y_4 represents the proportional use of Route 4. Finally, let V represent the expected value of the game to the base commander. Then,

$$X_2 + X_5 = 1 \quad , \quad Y_3 + Y_4 = 1 \ ,$$

$$1536X_2 + 191X_5 \geq V \quad ,$$

$$0\ X_2 + 542X_5 \geq V \quad ,$$

$$1536Y_3 + \ 0\ Y_4 \geq V \quad ,$$

$$191Y_3 + 542Y_4 \geq V \quad .$$

The solution of this system of equations and inequalities was found to be:

$$X_2 = 0.185 \quad , \quad X_5 = 0.815,$$

$$Y_3 = 0.288 \quad , \quad Y_4 = 0.712,$$

$$V \ = 422.$$

Which indicates that if both opponents use optimal strategies with respect to this mixed summary game, the base commander should use Doctrine Five 81.5 percent of the time and Doctrine Two the remainder and he can expect to detect an intruder at a range of 442 meters if the intruder uses the optimal strategy in selecting his infiltration routes. Because of the basic structure of game theory which led to this solution, it can be shown that the expected detection range will be no worse than 442 meters as long as the base commander follows the optimal strategy and will be even better than 442 meters if the intruder uses any but his optimal strategy for selecting infiltration routes.

Having given an example of methods of analysis that may be used to interpret the results obtained when using the modeling and simulation technique, the conclusions and areas of suggested study resulting from this study are presented in the next chapter.

VII. CONCLUSIONS AND EXTENSIONS

In this chapter the general conclusions resulting from this study of the doctrinal requirements for sensor system deployment in a base defense situation are presented. In addition, several areas for future study in this area are suggested.

A. CONCLUSIONS

The conclusions which have resulted from this study are of a general nature, since the use of only one officer to place the sensor systems in accordance with the various doctrines precluded recommendations of any individual doctrine within the framework of the situation presented. The construction and use of the model to evaluate the doctrines through computer simulation has led to the belief that this method is useful in obtaining relatively quick evaluations of alternative tactics or doctrines.

The method used in this study - modeling a base defense problem by simplifying a typical situation and simulating the problem with various doctrinal alternatives - requires careful attention to the assumptions, explicit and implicit, required; the location in which the problem is simulated; and the statement of the variables affecting the success of the various systems simulated. This approach necessitates tedious collection of data necessary to such a simulation,

especially that describing the physical site of the One of the limitations of an effort such as this is level of effort required to exercise the model in s different simulated terrains. However, once a model has been constructed and programmed for the computer, it offers a fairly easy avenue for exploring many variations of deployment schemes, system performance values, and decision rules. Carefully documented and stored on tape or cards, the programmed model can be exercised with little effort as a need arises.

The results obtained from the simulations of the various doctrines appear to indicate that a doctrine which does not restrict the placement of ground surveillance radars and night observation devices leads to a more effective employment of the systems. The unattended ground sensors, however, were most effective when deployed near base camp.

The following general conclusions are presented as a result of this study.

1. <u>The Method</u>

A fairly non-complex model used in conjunction with computer simulation can provide rapid indications of optimal tactics or doctrines to be used in small scale engagements.

2. <u>The Results</u>

A doctrine which does not restrict the placement of ground surveillance radars and night observation devices and requires the placement of unattended ground sensors near the base perimeter appears to be the best guidance for a base

commander in a defensive situation similar to that of this study. This conclusion results from the success with the line sensors obtained with those doctrines which did not limit line sensor deployment and the obvious lack of success with the remote sensors when using widely dispersed deployment. The highly successful deployment using Doctrine 5 supports both of these methods.

B. EXTENSIONS

Four areas for possible further study that were suggested during the preparation of this paper are described below.

1. Increased Sample Size

The placement of the systems in accordance with the various doctrines should be accomplished by several qualified officers before more specific judgements of doctrine value can be made. Although such placement is time consuming to the subject officer and to the data collector who must digitize the placements from overlays, several trials would be necessary in order to arrive at more specific conclusions.

2. Radar Range Law

The assumption of range independence in ground surveillance radar detection probability is questionable, especially when considering the dominance exhibited by three such devices in the results of this study. Only minor modification of the radar detection subroutine would be necessary to incorporate an inverse or inverse square law for radar detection.

3. <u>Parametric Study</u>

A parametric study of the relative importance of the three types of detection systems would be of interest. Combined with system cost data available in the catalog of STANO systems, this study could provide an indication of a cost effective mix of sensor systems in a base defense role.

4. <u>Command and Control</u>

As was mentioned earlier in this paper, incorporation of command and control limitations was not attempted in this study. A study of the optimal control procedures to be used with an integrated sensor system could be accomplished with this model with only minor modifications necessary. Such procedures should include decision rules for when to concentrate sensor coverage in an area, an optimal decision rule for determining when an actual detection has been made, and the alternatives available to the base commander upon detection of an intruder.

The simplified modeling technique used in conjunction with computer simulation appears to satisfy the requirement of the U.S. Army for "useful results in a few days or weeks." Retaining an awareness for the limitations of this method, the military analyst can, nonetheless, provide rapid and documented problem results to be used to reduce the number of unknowns in most questions involving tactics or military hardware.

APPENDIX A

SENSOR PLACEMENT INSTRUCTIONS

The instructions that follow were furnished to the officer who deployed the individual sensors in the eight simulation series described in this study. The officer was supplied with the instructions, a map of the area, and blank overlays, and had no knowledge of the preselected infiltration routes.

The purpose of this exercise is to place the components of an integrated sensor system for base defense in accordance with several different general doctrines for sensor use. The problem consists of detecting small infiltration groups advancing towards a base location from any point on the compass. You have been asked to aid in this test because you have knowledge of U.S. Army doctrine relating to base defense, but have no knowledge of preselected infiltration routes. Supplied with the detection equipment enumerated below, you will be required to place these systems in accordance with:

(1) The general doctrine supplied.
(2) The parameters of the systems.
(3) Knowledge of terrain from a map reconnaissance.
(4) The constraints of each type of system.

For each doctrine supplied please note on the accompanying overlay your placement of the following detection systems:

1. Ground Surveillance Radar.
    a. Symbol to be used: 90° where the base represents the exact location and the 90° represents the center scan orientation counterclockwise from East.
    b. Number to be utilized: 3.
    c. Parameters:
        (1) Range of Detection: Minimum of 400 meters, maximum of 3200 meters.
        (2) Antenna Mast: Antenna located on Mast of 20 meters height.
        (3) Sector Scan Width: 110°.
        (4) Foliage Penetration: Sixty percent of optimum in moderate foliage, twenty percent of optimum in heavy foliage.

(5) Allowable Locations: Not more than 500 meters from center of base camp noted on map.

2. Visual Detection Device.
   a. Symbol to be used: $\triangle$ 90°, where the center of the triangle represents the exact location and the 90° represents the center scan orientation counterclockwise from East.
   b. Number to be utilized: 4.
   c. Parameters:
      (1) Range of Detection: 1600 meters.
      (2) Sector: 90°
      (3) Foliage Penetration: eighty percent of optimum capability in moderate foliage, forty percent of optimum capability in heavy foliage.
      (4) Allowable Locations: Not more than 1200 meters from center of base camp noted on map.

3. Unattended Ground Sensors.
   a. Symbol to be used: o-o-o , UGS will be employed in strings of three located approximately 200 meters apart. The circles represent the sensors. Strings need not be straight.
   b. Number to be utilized: 10 strings.
   c. Parameters:
      (1) Radius of Detection: 40 meters.
      (2) Type: Seismic/Acoustic.
      (3) Allowable Locations: Deployed not further than 5000 meters from center of base camp.

<u>Map Reconnaissance</u>: Before placing the detection devices a reconnaissance of the Base Defense Area should be conducted utilizing the map provided. For the purposes of this exercise all indicated man-made structures on the map should be ignored with the exception of roads, bridges, and railroad tracks. The threat of infiltration into the Base Defense Area should be considered as uniform throughout 360° and constrained only by natural terrain channeling. Particular attention should be paid to likely avenues of approach and the line-of-sight problem in observing them. The Base Defense Area extends out 5000 meters from the center of the base camp as noted on the map.

<u>Doctrines to be Used in Placing the Detection Devices</u>: The detection devices provided as the Base Commander's resources should be placed in the best locations in accordance with each of the following doctrine statements. Some doctrine statements may be more specific than others. If the doctrine statement does not specify the exact method of employment of a system, employ it based on the system's parameters and your experience. Use the numbered overlays to denote system employment.

Doctrine #1. Radars and visual devices are used as a primary surveillance means of the area beyond the base perimeter. Isolated detection devices (UGS) are placed at or near areas masked from line-of-sight for early detection of intruders as they approach the base.

Doctrine #2. Radars and visual devices are used as a primary surveillance means. Unattended Ground Sensors should be utilized to cover likely avenues of approach for early warning regardless of line-of-sight considerations.

Doctrine #3. Radars should always be oriented towards only open terrain and overlapped in coverage if necessary. Visual devices and Unattended Ground Sensors should be used to cover the areas not considered for radar coverage.

Doctrine #4. Visual devices should always be oriented towards open terrain and overlapped in coverage if necessary. Radars and Unattended Ground Sensors should be used to cover the areas not considered for visual coverage.

Doctrine #5. Radars and visual devices are used as a primary surveillance means. Unattended Ground Sensors should be used near base camp to insure that no infiltration group penetrates the base itself.

Doctrine #6. Radars should always be oriented towards only open terrain and overlapped in coverage if necessary. Visual devices should be oriented towards terrain not covered by radars. Unattended Ground Sensors should be used to cover areas masked from line-of-sight for early detection of intruders.

Doctrine #7. Radars should always be oriented towards only open terrain and overlapped in coverage if necessary. Visual devices should be oriented towards terrain not covered by radars. Unattended Ground Sensors should be used near base camp to insure that no infiltration group penetrates the base itself.

Doctrine #8. Radar coverage should never overlap. Visual device coverage should never overlap. Unattended Ground Sensors should be used to cover likely avenues of approach.

When placing devices in accordance with one of the doctrine statements try not to compare the doctrine being used to any other doctrine stated above. Consider the statement as the only guidance received in placing the systems.

APPENDIX B

EXACT LOCATIONS OF DEVICES

TABLE X

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 1

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	53	51	0°
2	50	52	110°
3	49	50	210°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	57	51	45°
2	51	59	135°
3	46	41	225°
4	52	50	315°

Sensor String #	Sensor #1		Sensor #2		Sensor #3	
	X=	Y=	X=	Y=	X=	Y=
1	92	39	94	40	94	43
2	76	64	79	64	81	61
3	80	57	78	55	79	54
4	70	37	70	34	70	31
5	52	87	53	88	55	89
6	50	34	53	33	55	33
7	40	40	40	44	41	48
8	35	71	33	68	36	66
9	33	17	35	17	37	17
10	14	30	14	32	15	34

TABLE XI

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 2

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	52	51	315°
2	48	56	55°
3	50	50	190°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	52	51	150°
2	51	50	70°
3	46	43	250°
4	46	43	350°

Sensor String #	Sensor #1		Sensor #		Sensor #3	
	X=	Y=	X=	Y=	X=	Y=
1	90	45	90	47	89	48
2	76	66	78	65	79	64
3	76	54	78	55	79	56
4	69	37	69	40	70	41
5	52	45	53	47	55	48
6	51	20	51	22	52	24
7	42	60	43	61	43	64
8	41	44	42	46	42	49
9	34	17	36	18	37	19
10	14	29	14	32	15	35

TABLE XII

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 3

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	53	51	355°
2	51	53	65°
3	48	51	195°

Visual Device #	Location of Device		Center Scan Orientation
1	55	52	0°
2	48	55	125°
3	46	42	270°
4	51	50	290°

Sensor String #	Sensor #1		Sensor #2		Sensor #3	
	X=	Y=	X=	Y=	X=	Y=
1	93	43	91	44	89	44
2	81	59	81	61	80	62
3	74	18	74	15	73	13
4	69	37	69	40	70	42
5	55	29	56	31	57	33
6	51	40	49	39	48	38
7	37	68	39	66	40	65
8	35	17	37	18	38	20
9	14	30	14	32	15	34
10	4	59	6	59	8	59

TABLE XIII

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 4

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	48	54	125°
2	50	50	260°
3	51	51	280°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	51	51	350°
2	51	51	75°
3	48	54	175°
4	45	42	245°

Sensor String #	Sensor #1		Sensor #2		Sensor #3	
	X=	Y=	X=	Y=	X=	Y=
1	90	45	92	44	93	42
2	77	53	78	55	80	56
3	70	40	69	38	69	35
4	59	84	60	83	62	82
5	56	33	57	34	58	36
6	51	21	52	23	53	24
7	34	17	36	18	37	20
8	19	84	21	83	22	81
9	12	54	13	55	13	58
10	14	29	14	31	14	33

TABLE XIV

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 5

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	52	50	320°
2	50	52	65°
3	49	51	190°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	52	59	355°
2	48	55	130°
3	45	42	220°
4	51	51	310°

Sensor String #	Sensor #1		Sensor #2		Sensor #3	
1	65	44	66	45	66	46
2	61	52	63	52	64	53
3	66	34	67	36	68	37
4	53	46	54	47	56	49
5	54	52	55	51	56	50
6	49	56	51	55	52	54
7	48	38	49	39	51	40
8	46	49	46	51	46	52
9	43	59	43	61	42	63
10	41	47	42	49	42	51

TABLE XV

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 6

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	52	50	355°
2	49	55	60°
3	49	55	255°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	51	51	310°
2	51	51	45°
3	48	55	130°
4	46	42	255°

Sensor String #	Sensor #1		Sensor #2		Sensor #3	
	X=	Y=	X=	Y=	X=	Y=
1	89	48	90	46	91	44
2	76	63	77	64	79	64
3	75	53	77	54	79	55
4	70	38	70	40	70	42
5	73	13	74	14	75	16
6	55	29	56	30	56	32
7	42	61	43	63	43	64
8	34	16	36	18	37	19
9	12	56	13	57	14	59
10	15	28	15	30	15	32

TABLE XVI

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 7

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	53	50	270°
2	49	55	200°
3	48	56	10°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	48	56	50°
2	48	56	130°
3	51	51	20°
4	46	42	315°

Sensor String #	Sensor #1		Sensor #2		Sensor #3	
	X=	Y=	X=	Y=	X=	Y=
1	75	54	76	54	77	55
2	70	40	70	42	70	44
3	57	34	57	35	58	37
4	48	38	49	39	51	40
5	39	37	40	38	42	39
6	47	45	48	45	50	46
7	52	45	54	47	56	48
8	42	47	42	49	43	51
9	51	55	53	54	54	53
10	43	58	44	59	45	60

TABLE XVII

LOCATION OF DETECTION DEVICES UNDER DOCTRINE 8

Radar Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	56	52	320°
2	49	51	190°
3	48	46	55°

Visual Device #	Location of Device		Center Scan Orientation
	X=	Y=	
1	56	52	0°
2	51	50	300°
3	48	46	130°
4	47	42	225°

Sensor String #	Sensor #1		Sensor #2		Sensor #2	
	X=	Y=	X=	Y=	X=	Y=
1	89	46	90	48	91	50
2	78	56	79	57	80	59
3	69	37	69	39	70	42
4	64	53	66	54	68	55
5	50	21	51	23	53	24
6	33	18	35	19	37	20
7	41	46	41	48	42	50
8	42	58	43	60	43	63
9	12	58	14	58	16	58
10	14	30	14	32	15	34

```
C
C    COMPUTER PROGRAM FOR THE SIMULATION.
C
C
C     ***************************************************************
C     ***************************************************************
C
C     THIS PROGRAM IS CALLED THE BASE ORIENTED SENSOR SIMULA-
C     TION (BOSS) AND IS INTENDED TO TEST VARIOUS DEPLOYMENT
C     SCHEMES OF AN INTEGRATED SENSOR ARRAY CONTAINING THREE
C     RADARS, FOUR NIGHT OBSERVATION DEVICES, AND THIRTY RE-
C     MOTE SENSORS EMPLOYED IN A BASE DEFENSE ROLE. WITH
C     PROPER INPUT AS DESCRIBED IN THE BASIC STUDY, THE PRO-
C     GRAM WILL FURNISH RESULTS INDICATING THE HISTORY OF
C     SYSTEM SUCCESS AGAINST TWELVE DIFFERENT INFILTRATORS.
C     THE PROGRAM IS PRESENTLY SET FOR TWENTY-FIVE ITERATIONS
C     AND REQUIRES LESS THAN TWO MINUTES TO COMPILE AND EXE-
C     CUTE ON AN IBM 360/67.
C     THE FOLLOWING BUILTIN FUNCTIONS ARE REQUIRED IN ORDER
C     TO USE THE PROGRAM.
C     ARCTANGENT(ATAN)
C     SQUARE ROOT (SQRT)
C     ABSOLUTE VALUE, INTEGER (IABS)
C     INTEGER TO REAL (FLOAT)
C     RANDOM NUMBER (URN)
C
C     STATEMENTS PRECEDED AND FOLLOWED BY A LINE OF DOLLAR
C     SIGNS HAVE BEEN SHORTENED TO 60 COLUMNS FOR PUBLICATION
C     OF THIS DOCUMENT IN ORDER TO RUN THE PROGRAM, THESE
C     STATEMENTS MUST BE READJUSTED TO A 72 COLUMN FIELD.
C
C     ***************************************************************
C     ***************************************************************
C
       IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
       COMMON/ELEVAT/ELEV(100,100)
       COMMON/OBSERX/OBSX(7)
       COMMON/OBSERY/OBSY(7)
       COMMON/DEGREE/SCAN(7)
       COMMON/VEGIT/ZVEG(100,100)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
       COMMON/OSTRIN/OST1(3,2),OST2(3,2),OST3(3,2)8OST4(3,2),
      1OST5(3,2),OST6(3,2),OST7(3,2),OST8(3,2),OST9(3,2),OST1
      20(3,2)
       COMMON/IN1T4/INT1(48,2),INT2(42,2),INT3(45,2),INT4(49,
      12)
       COMMON/IN5T8/INT5(44,2),INT6(43,2),INT7(49,2),INT8(45,
      12)
       COMMON/IN9T12/INT9(50,2),INT10(49,2),INT11(47,2),INT12
      1(47,2)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
       COMMON/NVAL/N,NFLAG
       DIMENSION NNN(12)
C     READ 10,000 ELEVATION DATA POINTS AS DESCRIBED IN CHAP-
C     TERS II AND IV OF THE STUDY.
       READ(5,0001)ELEV
 0001 FORMAT(16F5.0)
C     READ 10,000 VEGETATION CHARACTERISTIC TYPES AS DESCRIB-
C     ED IN CHAPTERS II AND IV OF THE STUDY.
       READ(5,0200)ZVEG
 0200 FORMAT(80I1)
C     READ IN THE DIGITIZED INFILTRATION ROUTES (CHAPS II&IV)
       READ(5,0002)INT1
       READ(5,0002)INT2
       READ(5,0002)INT3
       READ(5,0002)INT4
       READ(5,0002)INT5
       READ(5,0002)INT6
       READ(5,0002)INT7
       READ(5,0002)INT8
       READ(5,0002)INT9
       READ(5,0002)INT10
```

```
      READ(5,0002)INT11
      READ(5,0002)INT12
 0002 FORMAT(26I3)
C    READ IN THE NUMBER OF SQUARES TRAVERSED BY EACH GROUP.
      READ(5,0003)NNN
 0003 FORMAT(12I2)
C    READ IN THE X&Y LOCATIONS OF THE LINE SENSORS (CHAP IV)
      READ(5,1209)OBSX
      READ(5,1209)OBSY
 1209 FORMAT(7I2)
C    READ IN THE CENTER SCAN ORIENTATIONS OF THE LINE SEN-
C    SORS (CHAP IV).
      READ(5,1210)SCAN
 1210 FORMAT(7F4.0)
C    READ IN THE LOCATIONS OF THE REMOTE SENSORS (CHAP IV).
      READ(5,0004)OST1
      READ(5,0004)OST2
      READ(5,0004)OST3
      READ(5,0004)OST4
      READ(5,0004)OST5
      READ(5,0004)OST6
      READ(5,0004)OST7
      READ(5,0004)OST8
      READ(5,0004)OST9
      READ(5,0004)OST10
 0004 FORMAT(6I3)
C     INITIALIZE THE RANDOM NUMBER GENERATOR.
      NR=-9
      RN=URN(NR)
C    BEGIN 25 ITERATIONS
      DO 7777 ITER=1,25
      N=0
      NFLAG=0
      IV=1
C    BEGIN MOVING INTRUDERS THROUGH THE BASE DEFENSE AREA,
C    ONE GROUP AT A TIME.
      NUM=NNN(1)
      DO 0100 IM=1,NUM
      X=INT1(IM,1)
      Y=INT1(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1100
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1100
 0100 CONTINUE
 1100 NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(2)
      DO 0101 IM=1,NUM
      X=INT2(IM,1)
      Y=INT2(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1101
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1101
 0101 CONTINUE
 1101 NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(3)
      DO 0102 IM=1,NUM
      X=INT3(IM,1)
      Y=INT3(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1102
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1102
 0102 CONTINUE
 1102 NFLAG=0
      N=0
      IV=1+IV
```

```
      NUM=NNN(4)
      DO 0103 IM=1,NUM
      X=INT4(IM,1)
      Y=INT4(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1103
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1103
0103  CONTINUE
1103  NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(5)
      DO 0104 IM=1,NUM
      X=INT5(IM,1)
      Y=INT5(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1104
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1104
0104  CONTINUE
1104  NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(6)
      DO 0105 IM=1,NUM
      X=INT6(IM,1)
      Y=INT6(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1105
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1105
0105  CONTINUE
1105  NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(7)
      DO 0106 IM=1,NUM
      X=INT7(IM,1)
      Y=INT7(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1106
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1106
0106  CONTINUE
1106  NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(8)
      DO 0107 IM=1,NUM
      X=INT8(IM,1)
      Y=INT8(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1107
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1107
0107  CONTINUE
      N=0
1107  NFLAG=0
      IV=1+IV
      NUM=NNN(9)
      DO 0108 IM=1,NUM
      X=INT9(IM,1)
      Y=INT9(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1108
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1108
0108  CONTINUE
1108  NFLAG=0
      N=0
      IV=1+IV
```

```
      NUM=NNN(10)
      DO 0109 IM=1,NUM
      X=INT10(IM,1)
      Y=INT10(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1109
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1109
 0109 CONTINUE
 1109 NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(11)
      DO 0110 IM=1,NUM
      X=INT11(IM,1)
      Y=INT11(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1110
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1110
 0110 CONTINUE
 1110 NFLAG=0
      N=0
      IV=1+IV
      NUM=NNN(12)
      DO 0111 IM=1,NUM
      X=INT12(IM,1)
      Y=INT12(IM,2)
      CALL INVIS(X,Y)
      IF(NFLAG.EQ.1) GO TO 1111
      CALL SENTEC(X,Y)
      IF(NFLAG.EQ.1) GO TO 1111
 0111 CONTINUE
 1111 NFLAG=0
 7777 CONTINUE
      STOP
      END


      SUBROUTINE INVIS(X,Y)
C    THIS SUBPROGRAM IS USED TO CHECK IF THE INTRUDER IS
C    WITHIN THE SCAN SECTOR, THE EFFECTIVE RANGE, AND THE
C    LINE-OF-SIGHT OF ONE OF THE LINE SENSORS.
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
      COMMON/ELEVAT/ELEV(100,100)
      COMMON/OBSERX/OBSX(7)
      COMMON/OBSERY/OBSY(7)
      COMMON/DEGREE/SCAN(7)
      COMMON/IVAL/IM,IV,I,IS
C    SEQUENTIAL SCAN SECTOR CHECK FOLLOWS.
 0001 XC=X-OBSX(1)
      YC=Y-OBSY(1)
      IF(XC.NE.0) GO TO 0105
      IF(YC.LT.0) GO TO 0106
      THETA=90.0
      GO TO 0107
 0106 THETA=270.0
      GO TO 0107
 0105 CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL COORD(FXC,FYC,THETA)
C    THE COORD SUBROUTINE CONVERTS FROM RADIANS TO DEGREES
C    AND LOCATES THE PROPER QUADRANT.
 0107 CONTINUE
      SCANP=SCAN(1)+55.0
      SCANM=SCAN(1)-55.0
      IF(SCANP.LE.360.0) GO TO 0104
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0102
```

```
      GO TO 0103
0104  IF(SCANM.GE.0.0) GO TO 0101
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0103
      IF(THETA.GT.SCANP) GO TO 0002
      GO TO 0103
0101  IF(THETA.GT.SCANP) GO TO 0002
0102  IF(THETA.LT.SCANM) GO TO 0002
0103  I=1
      GO TO 0020
0002  XC=X-OBSX(2)
      YC=Y-OBSY(2)
      IF(XC.NE.0) GO TO 0205
      IF(YC.LT.0) GO TO 0206
      THETA=90.0
      GO TO 0207
0206  THETA=270.0
      GO TO 0207
0205  CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL COORD(FXC,FYC,THETA)
0207  CONTINUE
      SCANP=SCAN(2)+55.0
      SCANM=SCAN(2)-55.0
      IF(SCANP.LE.360.0) GO TO 0204
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0202
      GO TO 0203
0204  IF(SCANM.GE.0.0) GO TO 0201
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0203
      IF(THETA.GT.SCANP) GO TO 0003
      GO TO 0203
0201  IF(THETA.GT.SCANP) GO TO 0003
0202  IF(THETA.LT.SCANM) GO TO 0003
0203  I=2
      GO TO 0020
0003  XC=X-OBSX(3)
      YC=Y-OBSY(3)
      IF(XC.NE.0) GO TO 0305
      IF(YC.LT.0) GO TO 0306
      THETA=90.0
      GO TO 0307
0306  THETA=270.0
      GO TO 0307
0305  CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL COORD(FXC,FYC,THETA)
0307  CONTINUE
      SCANP=SCAN(3)+55.0
      SCANM=SCAN(3)-55.0
      IF(SCANP.LE.360.0) GO TO 0304
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0302
      GO TO 0303
0304  IF(SCANM.GE.0.0) GO TO 0301
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0303
      IF(THETA.GT.SCANP) GO TO 0004
      GO TO 0303
0301  IF(THETA.GT.SCANP) GO TO 0004
0302  IF(THETA.LT.SCANM) GO TO 0004
0303  I=3
      GO TO 0020
0004  XC=X-OBSX(4)
      YC=Y-OBSY(4)
```

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      IF(XC.NE.0) GO TO 0405
      IF(YC.LT.0) GO TO 0406
      THETA=90.0
      GO TO 0407
0406  THETA=270.0
      GO TO 0407
0405  CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL COORD(FXC,FYC,THETA)
0407  CONTINUE
      SCANP=SCAN(4)+45.0
      SCANM=SCAN(4)-45.0
      IF(SCANP.LE.360.0) GO TO 0404
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0402
      GO TO 0403
0404  IF(SCANM.GE.0.0) GO TO 0401
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0403
      IF(THETA.GT.SCANP) GO TO 0005
      GO TO 0403
0401  IF(THETA.GT.SCANP) GO TO 0005
0402  IF(THETA.GT.SCANM) GO TO 0005
0403  I=4
      GO TO 0021
0005  XC=X-OBSX(5)
      YC=Y-OBSY(5)
      IF(XC.NE.0) GO TO 0505
      IF(YC.LT.0) GO TO 0506
      THETA=90.0
      GO TO 0507
0506  THETA=270.0
      GO TO 0507
0505  CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL COORD(FXC,FYC,THETA)
0507  CONTINUE
      SCANP=SCAN(5)+45.0
      SCANM=SCAN(5)-45.0
      IF(SCANP.LE.360.0) GO TO 0504
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0502
      GO TO 0503
0504  IF(SCANM.GE.0.0) GO TO 0501
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0503
      IF(THETA.GT.SCANP) GO TO 0006
      GO TO 0503
0501  IF(THETA.GT.SCANP) GO TO 0006
0502  IF(THETA.LT.SCANM) GO TO 0006
0503  I=5
      GO TO 0021
0006  XC=X-OBSX(6)
      YC=Y-OBSY(6)
      IF(XC.NE.0) GO TO 0605
      IF(YC.LT.0) GO TO 0606
      THETA=90.0
      GO TO 0607
0606  THETA=270.0
      GO TO 0607
0605  CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL COORD(FXC,FYC,THETA)
```

```
 0607 CONTINUE
      SCANP=SCAN(6)+45.0
      SCANM=SCAN(6)-45.0
      IF(SCANP.LE.360.0) GO TO 0604
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0602
      GO TO 0603
 0604 IF(SCANM.GE.0.0) GO TO 0601
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0603
      IF(THETA.GT.SCANP) GO TO 0007
      GO TO 0603
 0601 IF(THETA.GT.SCANP) GO TO 0007
 0602 IF(THETA.LT.SCANM) GO TO 0007
 0603 I=6
      GO TO 0021
 0007 XC=X-OBSX(7)
      YC=Y-OBSY(7)
      IF(XC.NE.0) GO TO 0705
      IF(YC.LT.0) GO TO 0706
      THETA=90.0
      GO TO 0707
 0706 THETA=270.0
      GO TO 0707
 0705 CONTINUE
      FXC=XC
      FYC=YC
      RATIO=FYC/FXC
      THETA=ATAN(RATIO)
      CALL CCORD(FXC,FYC,THETA)
 0707 CONTINUE
      SCANP=SCAN(7)+45.0
      SCANM=SCAN(7)-45.0
      IF(SCANP.LE.360.0) GO TO 0704
      SCANP=SCANP-360.0
      IF(THETA.GT.SCANP) GO TO 0702
      GO TO 0703
 0704 IF(SCANM.GE.0.0) GO TO 0701
      SCANM=SCANM+360.0
      IF(THETA.GT.SCANM) GO TO 0703
      IF(THETA.GT.SCANP) GO TO 0008
      GO TO 0703
 0701 IF(THETA.GT.SCANP) GO TO 0008
 0702 IF(THETA.LT.SCANM) GO TO 0008
 0703 I=7
      GO TO 0021
 0008 RETURN
C     DETERMINED TO BE WITHIN THE SCAN OF A DEVICE, A CHECK
C     IS NOW MADE TO SEE IF THE INTRUDER IS WITHIN THE EF-
C     FECTIVE RANGE OF THE DEVICE.
 0020 SSXY=(FXC)**2+(FYC)**2
      FRC=SQRT(SSXY)
      IF(FRC.LT.32.0) GO TO 0025
      GO TO (0002,0003,0004),I
 0021 SSXY=(FXC)**2+(FYC)**2
      FRC=SQRT(SSXY)
      IF(FRC.LT.16.0) GO TO 0025
      I=I-3
      GO TO (0005,0006,0007,0008),I
C     NOTE THAT VALUES OF 32.0 AND 16.0 REPRESENT RANGES OF
C     3200 AND 1600 METERS FOR RADARS AND VISUAL DEVICES.
C
C     INTRUDER IS IN THE SCAN SECTOR AND WITHIN RANGE OF A
C     DEVICE. A CHECK IS NOW MADE TO DETERMINE IF THE INTRUD-
C     ER IS WITHIN THE LINE-OF-SIGHT OF THE DEVICE.
C     INTERVISIBILITY CHECK FOLLOWS
 0025 IF(THETA.LE.45.0) GO TO 0031
      IF(THETA.GT.315.0) GO TO 0031
      IF(THETA.LE.135.0) GO TO 0032
      IF(THETA.LE.225.0) GO TO 0033
      IF(THETA.LE.315.0) GO TO 0034
C     STEP IN POSITIVE X DIRECTION FOLLOWS - CASE 1
```

```
0031 BASEL=(ELEV(OBSY(I),OBSX(I)))/3.28
     IF(I.LE.3) BASEL=BASEL+20.0
     TAREL=(ELEV(Y,X))/3.28
     RATIO=(TAREL-BASEL)/(FRC*100)
     PHI=ATAN(RATIO)
     IF(THETA.LE.45.0) GO TO 0131
     THETA=THETA-360.0
0131 THETA=THETA*0.01745
     J=X-OBSX(I)
     DO 0231 II=1,J
     XX=OBSX(I)+II
     YY=OBSY(I)+(II*(TAN(THETA)))
     XXC=II
     YYC=YY-OBSY(I)
     VTAR=(ELEV(YY,XX))/3.28
     FXXC=FLOAT(XXC)
     FYYC=FLOAT(YYC)
     SSXY=(FXXC)**2+(FYYC)**2
     RVT=SQRT(SSXY)
     RATIO=(VTAR-BASEL)/(RVT*100.0)
     PHIV=ATAN(RATIO)
     IF(PHIV.GT.PHI) GO TO 0990
0231 CONTINUE
     GO TO 0980
C    STEP IN POSITIVE Y DIRECTION FOLLOWS - CASE 2
0032 BASEL=(ELEV(OBSY(I),OBSX(I)))/3.28
     IF(I.LE.3) BASEL=BASEL+20.0
     TAREL=(ELEV(Y,X))/3.28
     RATIO=(TARLE-BASEL)/(FRC*100)
     PHI=ATAN(RATIO)
     THETA=(THETA-90.0)*0.01745
     J=Y-OBSY(I)
     DO 0132 II=1,J
     YY=OBSY(I)+II
     XX=OBSX(I)+(II*(TAN(THETA)))
     YYC=II
     XXC=XX-OBSX(I)
     VTAR=(ELEV(YY,XX))/3.28
     FXXC=FLOAT(XXC)
     FYYC=FLOAT(YYC)
     SSXY=(FXXC)**2+(FYYC)**2
     RVT=SQRT(SSXY)
     RATIO=(VATAR-BASEL)/(RVT*100.0)
     PHIV=ATAN(RATIO)
     IF(PHIV.GT.PHI) GO TO 0990
0132 CONTINUE
     GO TO 0980
C    STEP IN NEGATIVE X DIRECTION FOLLOWS - CASE 3
0033 BASEL=(ELEV(OBSY(I),OBSX(I)))/3.28
     IF(I.LE.3) BASEL=BASEL+20.0
     TAREL=(ELEV(Y,X))/3.28
     RATIO=(TAREL-BASEL)/(FRC*100)
     PHI=ATAN(RATIO)
     THETA=(THETA-180.0)*0.01745
     J=OBSX(I)-X
     DO 0133 II=1,J
     XX=OBSX(I)-II
     YY=OBSY(I)+(II*(TAN(THETA)))
     XXC=-II
     YYC=YY-OBSY(I)
     VTAR=(ELEV(YY,XX))/3.28
     FXXC=FLOAT(XXC)
     FYYC=FLOAT(YYC)
     SSXY=(FXXC)**2+(FYYC)**2
     RVT=SQRT(SSXY)
     RATIO=(VTAR-BASEL)/(RVT*100.0)
     PHIV=ATAN(RATIO)
     IF(PHIV.GT.PHI) GO TO 0990
0133 CONTINUE
     GO TO 0980
C    STEP IN NEGATIVE Y DIRECTION FOLLOWS - CASE 4
0034 BASEL=(ELEV(OBSY(I),OBSX(I)))/3.28
```

```
      IF(I.LE.3) BASEL=BASEL+20.0
      TAREL=(ELEV(Y,X))/3.28
      RATIO=(TAREL-BASEL)/(FRC*100)
      PHI=ATAN(RATIO)
      THETA=(THETA-270.0)*0.01745
      J=OBSY(I)-Y
      DO 0134 II=1,J
      YY=OBSY(I)-II
      XX=OBSX(I)+(II*(TAN(THETA)))
      YYC=-II
      XXC=XX-OBSX(I)
      VTAR=(ELEV(YY,XX))/3.28
      FXXC=FLOAT(XXC)
      FYYC=FLOAT(YYC)
      SSXY=(FXXC)**2+(FYYC)**2
      RVT=SQRT(SSXY)
      RATIO=(VTAR-BASEL)/(RVT*100.0)
      PHIV=ATAN(RATIO)
      IF(PHIV.GT.PHI) GO TO 0990
 0134 CONTINUE
      GO TO 0980
C    THE TARGET IS WITHIN LINE-OF-SIGHT. GO TO APPROPRIATE
C    DETECTION SUBROUTINE.
 0980 GO TO (0981,0981,0981,0982,0982,0982,0982),I
 0981 CALL RATECT(X,Y,FRC)
      GO TO(0002,0003,0004,0005,0006,0007,0008),I
 0982 CALL VITECT(X,Y,FRC)
 0990 GO TO(0002,0003,0004,0005,0006,0007,0008),I
      END


      SUBROUTINE COORD(FXC,FYC,THETA)
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
      THETA=THETA*(180.0/3.1416)
      IF(FXC.LT.0.0) GO TO 0101
      IF(FYC.LT.0.0) GO TO 0102
      RETURN
 0101 THETA=THETA+180.0
      RETURN
 0102 THETA=THETA+360.0
      RETURN
      END


      SUBROUTINE RATECT(X,Y,FRC)
C    THIS SUBROUTINE DETERMINES IF THE INTRUDER IS DETECTED
C    BY THE APPROPRIATE RADAR.
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
      COMMON/VEGIT/ZVEG(100,100)
      COMMON/IVAL/IM,IV,I,IS
      ZQ=1
      FRT=FRC*100.0
      RNGTBS=((X-51)**2)+((Y-51)**2)
      RNGTB=(SQRT(RNGTBS))*100.0
C    IF THE TARGET IS TOO CLOSE, IT CANNOT BE DETECTED.
      IF(FRT.LT.400.0) GO TO 1002
      RPD=.90
C    GET MOVEMENT VALUES FROM THE MOVEMENT SUBROUTINE.
      CALL MOVE(X,Y,ZMOVE,RADVEL,I,FRT,TIME)
C    IF TARGETS RADIAL VELOCITY IS LESS THAN 1 KM/HR, IT
C    CANNAT BE DETECTED.
      IF(RADVEL.LT.1.0) GO TO 1000
C    REDUCE PROB OF DETECTION FOR VEGETATION IF NECESSARY.
      ZZ=ZVEG(Y,X)
      VRED=1.0
      IF(ZZ.EQ.2) VRED=.60
      IF(ZZ.EQ.3) VRED=.20
      IF(ZZ.EQ.4) VRED=.50
      RPD=RPD*VRED
      RN=URN(1)
C    REDUCE PROB OF DETECTION FOR TARGET TIME AVAILABLE IF
C    NECESSARY.
```

```
      TRED=TIME/7.0
      IF(TRED.GT.1.0) TRED=1.0
      RPD=RPD*TRED
      IF(RN.LE.RPD) GO TO 1001
      GO TO 1002
 1000 CONTINUE
      GO TO 1003
C     IF RANDOM NUMBER-PROB OF DETECTION COMPARASION
C     INDICATES A DETECTION HAS BEEN MADE, THE DETECT SUB-
C     ROUTINE IS CALLED
 1001 CALL DETECT(X,Y,ZQ)
      GO TO 1003
 1002 CONTINUE
 1003 RETURN
      END


      SUBROUTINE VITECT(X,Y,FRC)
C     THIS SUBROUTINE DETERMINES IF THE INTRUDER IS DETECTED
C     BY THE APPROPRIATE NIGHT OBSERVATION DEVICE.
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
      COMMON/VEGIT/ZVEG(100,100)
      COMMON/IVAL/IM,IV,I,IS
      ZQ=2
      FRT=FRC*100.0
      RNGTBS=((X-51)**2)+((Y-51)**2)
      RNGTB=(SQRT(RNGTBS))*100.0
      VPD=.90
C     GET MOVEMENT VALUES FROM THE MOVEMENT SUBROUTINE.
      CALL MOVE(X,Y,ZMOVE,RADVEL,I,FRT,TIME)
      IF(FRT.LE.400.0) GO TO 0010
C     REDUCE THE PROB OF DETECTION FOR RANGE IF NECESSARY.
      VPD=VPD*(400.0/FRT)
 0010 CONTINUE
C     REDUCE PROB OF DETECTION FOR VEGETATION IF NECESSARY.
      IF(TIME.GE.5.0) GO TO 0011
      VPD=VPD*(TIME/5.0)
 0011 CONTINUE
      ZZ=ZVEG(Y,X)
      VRED=1.0
      IF(ZZ.EQ.2) VRED=.8
      IF(ZZ.EQ.3) VRED=.4
      IF(ZZ.EQ.4) VRED=.5
      VPD=VPD*VRED
      RN=URN(1)
      IF(RN.GT.VPD) GO TO 0012
C     IF RANDOM NUMBER-PROB OF DETECTION COMPARASION
C     INDICATES A DETECTION HAS BEEN MADE, THE DETECT SUB-
C     ROUTINE IS CALLED
      CALL DETECT(X,Y,ZQ)
      GO TO 0014
 0012 CONTINUE
 0014 RETURN
      END


      SUBROUTINE MOVE(X,Y,ZMOVE,RADVEL,I,FRT,TIME)
C     THE MOVEMENT SUBROUTINE FURNISHES INTRUDER MOVEMENT
C     VALUES REQUIRED BY THE RADAR AND VISUAL DETECTION
C     SUBROUTINES. THE PARAMETERS ARE THE RADIAL VELOCITY OF
C     THE TARGET WITH RESPECT TO THE DETECTING DEVICE AND THE
C     TIME THE TARGET IS AVAILABLE FOR DETECTION.
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
      COMMON/IVAL/IM,IV
      COMMON/VEGIT/ZVEG(100,100)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      COMMON/IN1T4/INT1(48,2),INT2(42,2),INT3(45,2),INT4(49,
     12)
      COMMON/IN5T8/INT5(44,2),INT6(43,2),INT7(49,2),INT8(45,
     12)
      COMMON/IN9T12/INT9(50,2),INT10(49,2),INT11(47,2),INT12
     1(47,2)
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C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
       COMMON/ELEVAT/ELEV(100,100)
       COMMON/OBSERX/OBSX(7)
       COMMON/OBSERY/OBSY(7)
       IF(IM.LE.1) GO TO 1000
       IMM=IM-1
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
       GO TO(0001,0002,0003,0004,0005,0006,0007,0008,0009,001
      10,0011,0012),IV
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 0001  XX=INT1(IMM,1)
       YY=INT1(IMM,2)
       GO TO 0013
 0002  XX=INT2(IMM,1)
       YY=INT2(IMM,2)
       GO TO 0013
 0003  XX=INT3(IMM,1)
       YY=INT3(IMM,2)
       GO TO 0013
 0004  XX=INT4(IMM,1)
       YY=INT4(IMM,2)
       GO TO 0013
 0005  XX=INT5(IMM,1)
       YY=INT5(IMM,2)
       GO TO 0013
 0006  XX=INT6(IMM,1)
       YY=INT6(IMM,2)
       GO TO 0013
 0007  XX=INT7(IMM,1)
       YY=INT7(IMM,2)
       GO TO 0013
 0008  XX=INT8(IMM,1)
       YY=INT8(IMM,2)
       GO TO 0013
 0009  XX=INT9(IMM,1)
       YY=INT9(IMM,2)
       GO TO 0013
 0010  XX=INT10(IMM,1)
       YY=INT10(IMM,2)
       GO TO 0013
 0011  XX=INT11(IMM,1)
       YY=INT11(IMM,2)
       GO TO 0013
 0012  XX=INT12(IMM,1)
       YY=INT12(IMM,2)
 0013  CONTINUE
C     COMPUTE DISTANCE TRAVELED
       DISS=((X-XX)**2)+((Y-YY)**2)
       DIS=(SQRT(DISS))*100.0
C     GRADIENT IS CALCULATED
       PREVHT=ELEV(YY,XX)
       PRESHT=ELEV(Y,X)
       DIFHT=PRESHT-PREVHT
       IF(DIFHT.GE.0.0) GO TO 0014
       DIFHT=DIFHT*(-1.0)
C     REDUCE THE BASIC VELOCITY OF THE INTRUDER IN ACCORDANCE
C     WITH THE SLOPE OF THE TERRAIN.
 0014  GRAD=(DIFHT/3.28)/DIS
       GRED=1.0
       IF(GRAD.GT.0.05) GRED=.90
       IF(GRAD.GT.0.20) GRED=.70
       IF(GRAD.GT.0.40) GRED=.50
C     A BASIC VELOCITY OF 3 KM/HR IS ASSUMED.
       BASVEL=3.0
       VEL=BASVEL*GRED
C     REDUCE THE BASIC VELOCITY OF THE INTRUDER IN ACCORDANCE
C     WITH THE VEGETATION IN THE AREA.
       ZZ=ZVEG(Y,X)
       VRED=1.0
       IF(ZZ.EQ.2) VRED=.90
       IF(ZZ.EQ.3) VRED=.70
       IF(ZZ.EQ.4) VRED=.50
```

```
      VEL=VEL*VRED
C     COMPUTE THE TIME REQUIRED FOR THIS MOVE.
      TIME=((DIS/1000.0)/VEL)*60.0
C     NOW FIGURE RADIAL VELOCITY
      FFRCS=((OBSX(I)-XX)**2)+((OBSY(I)-YY)**2)
      FFRC=(SQRT(FFRCS))*100.0
      RDIF=FFRC-FRT
      RADVEL=(RDIF/DIS)*VEL
      IF(DIS.LT.110.0) ZMOVE=1
      IF(DIS.GE.110.0) ZMOVE=2
 1000 RETURN
      END


      SUBROUTINE SENTEC(X,Y)
C     THE SENSOR DETECTION SUBRCUTINE DETERMINES EACH MOVE
C     WHETHER THE INTRUDER IS DETECTED BY A REMOTE SENSOR.
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      CCMMON/OSTRIN/OST1(3,2),OST2(3,2),OST3(3,2)8OST4(3,2),
     1OST5(3,2),OST6(3,2),OST7(3,2),OST8(3,2),OST9(3,2),OST1
     20(3,2)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      COMMON/IVAL/IM,IV,I,IS
      ZQ=3
C     TO SAVE TIME, A FIRST ROUGH CHECK IS MADE TO SEE IF THE
C     INTRUDER IS WITHIN 400 METERS IN BOTH THE X&Y DIRECTION
C     OF THE CENTER SENSOR OF EACH SENSOR STRING.
      XDIF=X-OST1(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0002
      YDIF=Y-OST1(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0002
      GO TO 0011
 0002 XDIF=X-OST2(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0003
      YDIF=Y-OST2(2,2)
      YDIF=IABS(YCIF)
      IF(YDIF.GT.4) GO TO 0003
      GO TO 0012
 0003 XDIF=X-OST3(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0004
      YDIF=Y-OST3(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0004
      GO TO 0013
 0004 XDIF=X-OST4(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0005
      YDIF=Y-OST4(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0005
      GO TO 0014
 0005 XDIF=X-OST5(2,1)
      XDIF=IABS(XCIF)
      IF(XDIF.GT.4) GO TO 0006
      YDIF=Y-OST5(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0006
      GO TO 0015
 0006 XDIF=X-OST6(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0007
      YDIF=Y-OST6(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0007
      GO TO 0016
 0007 XDIF=X-OST7(2,1)
      XDIF=IABS(XDIF)
```

```
      IF(XDIF.GT.4) GO TO 0008
      YDIF=Y-OST7(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0008
      GO TO 0017
0008  XDIF=X-OST8(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0009
      YDIF=Y-OST8(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0009
      GO TO 0018
0009  XDIF=X-OST9(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 0010
      YDIF=Y-OST9(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 0010
      GO TO 0019
0010  XDIF=X-OST10(2,1)
      XDIF=IABS(XDIF)
      IF(XDIF.GT.4) GO TO 9999
      YDIF=Y-OST10(2,2)
      YDIF=IABS(YDIF)
      IF(YDIF.GT.4) GO TO 9999
      GO TO 0020
C     IF THE INTRUDER IS WITHIN THE REQUIRED 400 METERS, THE
C     COORDINATES OF ALL THE SENSORS OF THAT STRING ARE RE-
C     TRIEVED.
0011  IS=1
      X1=OST1(1,1)
      X2=OST1(2,1)
      X3=OST1(3,1)
      Y1=OST1(1,2)
      Y2=OST1(2,2)
      Y3=OST1(3,2)
      GO TO 9998
0012  IS=2
      X1=OST2(1,1)
      X2=OST2(2,1)
      X3=OST2(3,1)
      Y1=OST2(1,2)
      Y2=OST2(2,2)
      Y3=OST2(3,2)
      GO TO 9998
0013  IS=3
      X1=OST3(1,1)
      X2=OST3(2,1)
      X3=OST3(3,1)
      Y1=OST3(1,2)
      Y2=OST3(2,2)
      Y3=OST3(3,2)
      GO TO 9998
0014  IS=4
      X1=OST4(1,1)
      X2=OST4(2,1)
      X3=OST4(3,1)
      Y1=OST4(1,2)
      Y2=OST4(2,2)
      Y3=OST4(3,2)
      GO TO 9998
0015  IS=5
      X1=OST5(1,1)
      X2=OST5(2,1)
      X3=OST5(3,1)
      Y1=OST5(1,2)
      Y2=OST5(2,2)
      Y3=OST5(3,2)
      GO TO 9998
0016  IS=6
      X1=OST6(1,1)
      X2=OST6(2,1)
```

```
      X3=OST6(3,1)
      Y1=OST6(1,2)
      Y2=OST6(2,2)
      Y3=OST6(3,2)
      GO TO 9998
 0017 IS=7
      X1=OST7(1,1)
      X2=OST7(2,1)
      X3=OST7(3,1)
      Y1=OST7(1,2)
      Y2=OST7(2,2)
      Y3=OST7(3,2)
      GO TO 9998
 0018 IS=8
      X1=OST8(1,1)
      X2=OST8(2,1)
      X3=OST8(3,1)
      Y1=OST8(1,2)
      Y2=OST8(2,2)
      Y3=OST8(3,2)
      GO TO 9998
 0019 IS=9
      X1=OST9(1,1)
      X2=OST9(2,1)
      X3=OST9(3,1)
      Y1=OST9(1,2)
      Y2=OST9(2,2)
      Y3=OST9(3,2)
      GO TO 9998
 0020 IS=10
      X1=OST10(1,1)
      X2=OST10(2,1)
      X3=OST10(3,1)
      Y1=OST10(1,2)
      Y2=OST10(2,2)
      Y3=OST10(3,2)
C     NOW A CHECK IS MADE TO DETERMINE IF THE TARGET IS IN
C     THE SAME GRID SQUARE AS A SENSOR. IF IT IS, COMPAR-
C     ASION BETWEEN A RANDOM NUMBER AND THE PROB OF DETECTION
C     IS MADE TO DETERMINE IF THE INTRUDER HAS BEEN DETECTED.
 9998 XD=X1-X
      YD=Y1-Y
      IF(XD.NE.0) GO TO 9997
      IF(YD.NE.0) GO TO 9997
      GO TO 9995
 9997 XD=X2-X
      YD=Y2-Y
      IF(XD.NE.0) GO TO 9996
      IF(YD.NE.0) GO TO 9996
      GO TO 9995
 9996 XD=X3-X
      YD=Y3-Y
      IF(XD.NE.0) GO TO 9994
      IF(YD.NE.0) GO TO 9994
 9995 RN=URN(1)
      IF(RN.GT.0.4526) GO TO 9994
C     IF A DETECTION OCCURS, THE DETECT SUBROUTINE IS
C     NOTIFIED.
      CALL DETECT(X,Y,ZQ)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 9994 GO TO(0002,0003,0004,0005,0006,0007,0008,0009,0010,999
     19),IS
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 9999 RETURN
      END
```

```
      SUBROUTINE DETECT(X,Y,ZQ)
C     THIS SUBROUTINE APPLIES THE '2 DETECTION, 500 METER'
C     DECISION RULE TO THE DETECTIONS ACQUIRED. WHEN, AND IF,
C     THE RULE IS SATISFIED FOR A PARTICULAR INTRUDER, A
C     FORMAL DETECTION IS DECLARED AND THE PERTINENT INFORM-
C     ATION IS PRINTED.
      IMPLICIT INTEGER*2(Z),INTEGER*4(O,X,Y)
      COMMON/IVAL/IM,IV,I,IS
      COMMON/NVAL/N,NFLAG
      DIMENSION DET(10,3)
C     COMPUTE AND STORE INFORMATION CONCERNING THE DETECTION.
      RNGTBS=((X-51)**2)+((Y-51)**2)
      RNGTB=(SQRT(RNGTBS))*100.0
      N=N+1
      DET(N,1)=RNGTB
      GO TO (0001,0002,0003),ZQ
 0001 DET(N,2)=1.0
      DET(N,3)=I
      GO TO 0004
 0002 DET(N,2)=2.0
      DET(N,3)=I-3
      GO TO 0004
 0003 DET(N,2)=3.0
      DET(N,3)=IS
 0004 IF(N.GT.1) GO TO 0005
      RETURN
C     CHECK FOR SATISFACTION OF THE DECISION RULE.
 0005 NM=N-1
      RDIF=DET(NM,1)-DET(N,1)
      IF(RDIF.LE.500.0) GO TO 0006
      RETURN
C     NOTIFY THE MAIN PROGRAM OF A FORMAL DETECTION.
 0006 NFLAG=1
      AA=DET(NM,2)
      XA=AA
      R=DET(N,1)
C     PRINT PERTINENT INFORMATION.
      WRITE(6,0008)IV,R
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 0008 FORMAT('0',10X,'INTRUDER GROUP ',I2,' WAS DETECTED AT
     1RANGE ',F6.1,'. DETECTION DEVICES WERE ',//)
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      K=N
      KK=NM
      GO TO (009,0010,0011),ZQ
 0009 WRITE(6,0012)DET(K,3)
 0012 FORMAT(31X,'RADAR NUMBER ',F2.0,//)
      GO TO 0015
 0010 WRITE(6,0013)DET(K,3)
 0013 FORMAT(31X,'VISUAL DEVICE NUMBER ',F2.0,//)
      GO TO 0015
 0011 WRITE(6,0014)DET(K,3)
 0014 FORMAT(31X,'SENSOR STRING NUMBER ',F3.0,//)
 0015 WRITE(6,0016)
 0016 FORMAT(41X,'AND',//)
      GO TO (0017,0018,0019),XA
 0017 WRITE(6,0012)DET(KK,3)
      GO TO 0020
 0018 WRITE(6,0013)DET(KK,3)
      GO TO 0020
 0019 WRITE(6,0014)DET(KK,3)
 7777 CONTINUE
 0020 DO 0007 ID=1,N
      DET(ID,1)=0
      DET(ID,2)=0
      DET(ID,3)=0
 0007 CONTINUE
      N=0
      RETURN
      END
```

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13. ABSTRACT

A mathematical model describing the detection activities of an integrated sensor array containing radars, visual devices and remote sensors is presented. Using the programmed model, infiltration of a base defense area is simulated with a computer and results are obtained for various array deployment schemes. A comparative analysis of these results is conducted using game and decision theory and a general conclusion concerning an optimal sensor deployment doctrine is derived. The complete computer program is described in the text of the study and is contained as an appendix.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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UNATTENDED GROUND SENSOR (UGS)						
NIGHT OBSERVATION DEVICE (NOD)						
GROUND SURVEILLANCE RADAR (GSR)						
BASE DEFENSE						
STANO						
SIMULATION						
INTERVISIBILITY						

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c.1
An investigation of alternative deplyoment doctrines for an integrated sensor array in base defense.